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Expandable Floating Bases

FINAL REPORT

Goodyear Aerospace Corporation

GER 15491

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GOODYEAR AEROSPACE CORPORATION

AKRON, OHIO 44315

FINAL TECHNICAL REPORT

EXPANDABLE FLOATING BASES

GER 15491 14 January 1972

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LIST OF DRAWINGS

In accordance with the contract statement of work, revised by Amendment 1, the following drawings prepared under this contract have been submitted:

GAC drawing 71QS1073 (15 sheets) Primary Design Concept

Sheet 1	-	Preliminary Concept
Sheet 2	-	Fabric Strap Midpoint (truss attach)
Sheet 3	-	Fabric Strap Lower Point (truss attach)
Sheet 4	-	Tabulated Requirements
Sheet 5	-	Float Tube Dome Collar
Sheet 6	-	Deck Panel
Sheet 7	-	Attenuator
Sheet 8	-	Intermediate Point (truss attach)
Sheet 9	-	Deck to Float Attachment
Sheet 10	-	Float Tube
Sheet 11	-	Deck Panel Attachment (bolted)
Sheet 12	-	Seven Tube Cluster Float
Sheet 13	-	Deck Panel Attachment (key)
Sheet 14	-	Float Tube Cap & Panel Attachment (flat)
Sheet 15	-	Float Tube Lower Cap & Attenuator Attachment (flat)

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LIST OF ABBREVIATIONS

ARPA	-	Advanced Research Projects Agency
Av.	-	Average
c.g.	-	Center of Gravity
Exc.	-	Exceeding
eq.	-	Equalling; Equation
F.	-	Fahrenheit
Ft.	-	Feet
Fwd.	-	Forward
GAC	-	Goodyear Aerospace Corporation
Ht.	-	Height
IBM	-	International Business Machines
in.	-	Inches
L	-	Length
Ldg.	-	Landing
Lb.	-	Pounds
Max.	-	Maximum
N. Mi.	-	Nautical Miles
ONR	-	Office of Naval Research
Prob.	-	Probability
p.s.f	-	Pounds per Square Foot
p.s.i.	-	Pounds per Square Inch
Ref.	-	Reference
sec.	-	Second
T	-	Time
T.O.	-	Take Off
Ult.	-	Ultimate
vs	-	Versus
W	-	Width
wt.	-	Weight

LIST OF SYMBOLS

A_c	Cross section area of floats
a	Length
BM	Metacentric height
b	Column or float row spacing
b_v	Vertical column or float brace spacing
C_D	Velocity drag coefficient
C_M	Inertial drag coefficient
D	Column or float diameter
d	Draft; distance between columns
E	Young's modulus
F	Wave side force per unit length
F.S.	Factor of safety
F_{tv}	Ultimate tensile strength
g	Acceleration due to gravity
H_M	Wave height
$H_{1/10}$	Average of the 1/10 highest waves
h_A	Height of metacenter above S.W.L.
h_d	Deck height above S.W.L.
h_s	Sandwich panel thickness
I	Moment of inertia
k	$2\pi Ld$
L	Column length
Ld	Wave length
ℓ	Distance from S.W.L. to bottom of float
M	Bending moment
M_B	Righting moment
M_{MB}	Maximum beam moment
M_W	Overturning moment
m	Column spacing/diameter ratio number

LIST OF SYMBOLS (cont'd)

N_ϕ	Axial stress
N_θ	Hoop stress
n	Load factor; number
n p	Strength reduction factor for pressure
n w	Strength reduction factor for transient wave
P	Axial load
P_A	Column axial load
P_D	Column inflation pressure
P_E	Euler column buckling load
p	Pressure
p_{AC}	Pressure governed by axial compression
p_{AT}	Pressure governed by axial tension
p_{HT}	Pressure governed by hoop tension
p_{TR}	Pressure under a wave trough
R	Radius of equivalent circular plate; reaction
S.W.L.	Still water line
T	Period
W	Weight
W_ℓ	Eccentric deck load
W_s	Structure weight
W_w	Ballast water weight
w	Distributed load
X	Coordinate
Z	Still water displacement depth
k	Coefficient
ρ	Density
ρ'	Pseudo fluid density
r	Float radius
θ	Angle of tilt

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SECTION I
PROGRAM SUMMARY

1 - 1. During the past year and a half, Goodyear Aerospace Corporation (GAC) has conducted an investigation to determine the technical feasibility of utilizing large expandable structures which can be joined together to form a Floating Island Base. This program has been conducted under the contractual and technical direction of the Ocean Science and Technology Division, Office of Naval Research, Department of the Navy, and was sponsored by the Advanced Research Projects Agency of the Department of Defense.

1 - 2. The objectives in using expandable structures in this application were to develop a floating base which could be packaged, transported, and erected employing a minimum of time and effort. The missions for a base of this type would be of a temporary nature and therefore the island must also be capable of being repackaged for redeployment.

1 - 3. The use of expandable structures has been demonstrated in a number of applications by such items as tires, airships, inflated life rafts, inflated antenna masts, and an inflatable airplane called the INFLATOPLANE*. The collapsibility of inflated structures potentially permits construction of vehicles or components that will occupy only a small percentage of their inflated operating volume when packaged. This minimizes the logistics problems of storage space, handling, and transporting.

1 - 4. Another inherent advantage of expandable structures is the ability to withstand and recover from momentary overloads. This feature of absorbing excess energy by buckling and then returning to shape can be considered a safety characteristic and will reduce maintenance and repair costs.

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*TM, Goodyear Aerospace Corporation, Akron, Ohio 44315

1 - 5. Many marine structures require special considerations such as marine fouling, wave slap, impact, low weight, packageability, flexibility, buoyancy, and various other operational requirements which may be included in their design when using expandable structures.

1 - 6. Since air under pressure is contained within expandable structures to provide strength and shape, a flotation capability results with no additional structural weight or complexity. For marine applications, this flotation capability can serve a useful mission as well as a safety measure.

1 - 7. Above all, one of the properties that allows extended performance capability is the high strength-to-weight ratio of expandable structures. Resistance to special environmental conditions can be designed into the structure. Thus, when the design parameters have been established, resistance to fungus and marine growth can be coated on or compounded into the expandable material from which the item is fabricated.

1 - 8. Other objectives of this specific contract were to develop technology in the area of both design and materials. To accomplish these objectives, the investigation was made by considering the environmental operating and survival conditions, platform stability, platform mobility, requirements and capabilities of expandable structure in this application, cost, sizes of components, material life, transportation and erection procedures.

1 - 9. The basic configuration studied utilizes vertical floats to support a platform for a mission above the ocean surface. This approach provides a stable platform even in heavy seas. One method of accomplishing this result is to extend the floats below the water surface to a depth where the water motion, due to wave action is reduced. These very long columns have a low natural frequency

which assures motion isloation from the forces produced by waves. However, long columns require large quantities of material which add to the cost, weight, transportation, and erection problems. A more efficient float design was attempted during this program by combining the advantages of relatively low natural frequency together with attenuated wave exciting forces. This type of float or column design has been approached by engineering the float shape to produce appropriate virtual mass and damping.

1 - 10. To begin this program, the environmental conditions of the open ocean were investigated to determine those parameters which would provide necessary information for the design of an Expandable Floating Base.

1 - 11. Using this information several configurations evolved and were analyzed for their adequacy in performing the functions believed required in an Expandable Floating Base. This analysis was in the form of a parametric study to determine the best column spacing, column diameter, corresponding deck thickness, and maximum aircraft loadings. In this process the following interesting structural problems were encountered and solved:

a) The theory of a plate on elastic foundation was extended to cover the floating platform. An existing computer program could then be utilized.

b) The theory of shear deflections in a plate on elastic foundation was developed. A computer program was used for numerical results.

c) The ultimate load capacity of an inflated plate loaded over a small central area was determined.

d) Optimum shear web angles were determined for a lobed inflated plate.

e) Bonded sandwich panel-inflated plate load-sharing was determined.

f) Optimum deck plate shapes for maximum and minimum bending transfer were investigated.

g) The transverse and longitudinal stiffness of lobed inflated plates was evaluated, both in bending and shear.

h) The column bracing was analyzed to determine its contribution to the stiffness of the deck.

i) The capabilities of a single inflated plate, two inflated plates placed transverse to one another, a design with two layers of inflated cylinders acting as an inflated plate, and a deck entirely of hexagonal sandwich panels, were compared.

j) The vertical floats were analyzed as beam-columns.

k) A computer program for analysis of a plate supported on an array of columns and carrying a concentrated load was written.

1 - 12. Each of the configurations analyzed had both advantages and disadvantages. However, one configuration was selected which would permit a concentration of effort on the one item common to all and on which the entire Expandable Floating Base concept was believed contingent. This item is the expandable vertical floats. The configuration selected for detailed analysis of the base is a sandwich panel deck structure supported off the water by the expandable vertical floats. This configuration is shown in Figure 1.

1 - 13. Following these decisions, effort was concentrated on determining the proper size of the components of the floating base to withstand the loads and sea conditions established earlier. In this effort attention was directed toward strengths, weights,

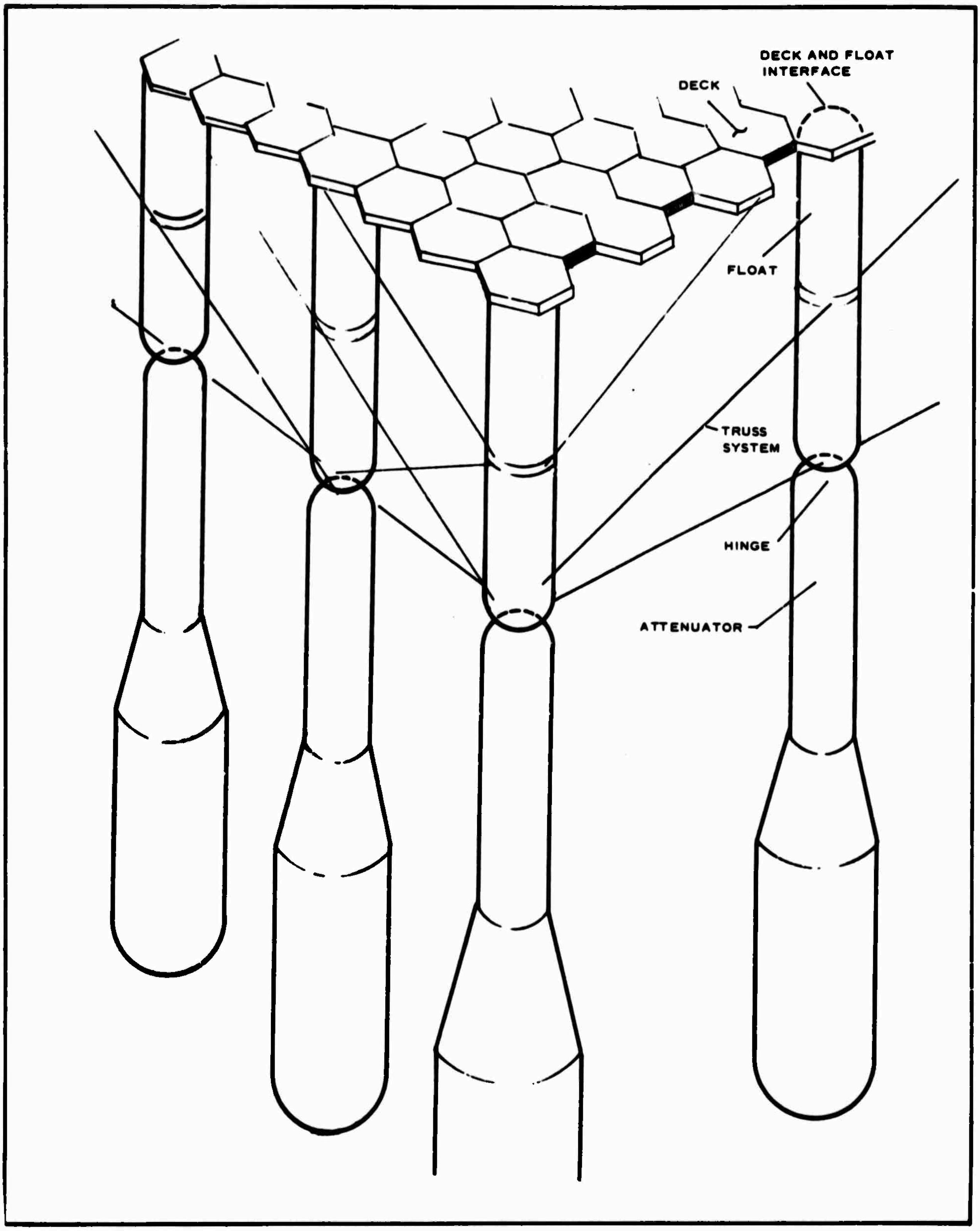

Figure 1 - Expandable Floating Base Concept

thicknesses, packageability, transportability, and the cost of manufacturing Expandable Floating Bases. Also considered were the stability and overall size of these islands and how they would be erected on the ocean surface. In support of this, several preliminary designs of components believed to be critical to the concept were produced.

1 - 14. Further analyses and model tests were conducted by Stevens Institute of Technology to verify loads assumed early in the investigation. The response of various shaped floats to waves was determined by tests on models of 1:57.6 design size. In addition to the investigation of individual floats, small arrays of floats and a small section of an island model which was 6 floats wide by 35 floats in length, were also tested in a towing basin. Certain general findings of the tests can be presented:

(1) The vertical wave-induced force is modified b an increase in an added-mass type force component. This is significant for higher frequencies and accounts for about a 30% increase above the isolated float results for the fatter of the two floats studied. The results for vertical (lift) force on a rather short, full float (whether isolated or in the middle of a 25 float array) show an increase in force at high frequency.

The introduction of a ten-foot diameter damping plate at the junction of the conical transition piece and the upper float produced only a minor increase in lift force at high frequency. Rather similar results were obtained with a deeper, more slender float, but when damping plates having a 13.5-foot diameter were fitted to the lower end of the floats, the wave forces were dramatically increased. Apparently this increase was due to a drag-type component in phase with the vertical

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wave velocity. The forces on the interior float elements of the array were found to be virtually the same on each float, but the floats in the forward row (near the wave generator) and in the aft row were close to the results for isolated floats.

(2) When horizontal forces were measured on floats (isolated and in array), it was found (somewhat surprisingly) that little or no interaction occurs for this component of force and the floats in array experience essentially the same side force as the isolated floats.

(3) The utilization of a hinge which permits the lower end of the attenuator to oscillate like a pendulum under the action of the waves was also investigated. The hinge permits side loads (due to waves) to be absorbed by the pendulum-like motion of the attenuator and thus prevents them from being completely transmitted to the Floating Base connecting structure by way of bending moments in the float. This action reduces the strength requirements of the inflated floats and, consequently, weight and cost.

The side forces measured on the float when a hinge was introduced at a location 23-ft below the water line, are remarkably lower than without the hinge, and it is important to note that the hinge had virtually no effect on the vertical float force due to waves.

(4) Tests in irregular waves were also performed with the island model. Waves having significant heights of 6.9, 10, 15, and 30 feet and spectral distributions like the Pierson-Moskowitz formulation were generated. These significant heights correspond to the less precise seafarer's designation of Sea States 4, 5, 6, and 7 respectively.

1 - 15. The particular float geometry (which was selected on the basis of individual float tests) used for these floats is not suitable for the Floating Expandable Base. Although according to the unmodified theory it satisfies the heave motion criteria, the experiments demonstrate that it does not perform sufficiently like the theory. A somewhat deeper, more slender float design is expected to perform in conformance to the criteria.

1 - 16. The results of a systems analysis, which was also parametric but within a narrower scope, are also included. In this systems analysis three design sea states were compared: 0, 5, and 7. The zero state can be used to isolate the influence of the aircraft weight from the effect of waves on the design. The hexagonal panel deck design was assumed and attention was concentrated mainly on the effects of ocean waves and the design of the attenuators and the understructure. The effect of cost as a function of load and sea state was then compared.

1 - 17. The analytical studies and model tests conducted to date in the performance of this contract have not revealed any insurmountable obstacles which would make the Expandable Floating Base not feasible.

1 - 18. Although the exact float-attenuator configuration has not been established for a specific base by this investigation, the information can be provided when a design requirement based on a mission for a base of this type has been given. A mission or use needs to be stated since the amount of attenuation of deck motion in a design sea state is directly related to the size and shape of the components below the water surface, and to some extent to the size of the base. However, a program is recommended to demonstrate the technical feasibility for this concept in the areas of fabrication, erection and test. It is further recommended that this program begin as soon as possible.

SECTION II
INTRODUCTION

2 - 1. Under the contractual and technical direction of the Ocean Science and Technology Division, Office of Naval Research, Department of the Navy, and sponsored by the Advanced Research Projects Agency of the Department of Defense, Goodyear Aerospace Corporation (GAC) has conducted a program to investigate the technical feasibility of large expandable structures that can be joined together to form a floating island base. One anticipated use of such an island for consideration during this program has been as an airfield capable of handling large cargo aircraft.

2 - 2. The expandable structures approach to the floating base appears to be suited ideally to the flotation, loading, transporting, and quick reaction requirements. The objective of this program was, therefore, to develop technology in the areas of both design and materials compatible with the requirements of a floating base in the open sea.

2 - 3. A primary design requirement for this program involved the placing of a floating platform on an open ocean in a reasonable length of time and at a reasonable cost, and maintaining the platform in this environment to perform some useful mission. Important parts of the requirement included size of components, maximum environment operating and survival conditions, platform stability, platform mobility, structural considerations, module size, material life, transportation to site, erection on site, and mooring or station keeping. Some areas, such as final platform size and mission compatibility, were not believed to be immediately urgent and were postponed for later consideration. The philosophy used in this approach was that, regardless of the end application of the floating island, there is a sufficient commonality of mission

requirements to arrive at the design of a basic module that is compatible with many applications. As the overall program continues design studies are recommended to adapt the modular arrangement to mission applications of particular interest.

2 - 4. The floating island concept in this program has been based on modular units, or building blocks, that can be readily transported to the site and easily erected. The feasibility of and requirements for disassembly and repacking for re-deployment from one operational site to another has also been considered. The size of the modular type units is compatible with present manufacturing processes and transportation methods. This approach permits interchangeability of component units and provides for preventive maintenance.

2 - 5. This report, in accordance with Section F - Technical Reports, paragraph B (6) of the Contract Schedule, represents the Final Report. Its purpose is to present a concise and factual discussion of the technical findings and accomplishments which resulted during this program.

2 - 6. The basic configuration studied utilizes vertical floats to support a platform for a mission above the ocean surface. The use of slender vertical floats in this application affords a comfortable and stable working platform with small motions even in heavy seas. A thorough discussion of this concept and its development, as applied to aircraft for open-ocean operation is presented in Reference 1. One method of accomplishing this result is to extend the floats below the water surface to a depth where the water motion, due to wave action, is reduced. These very long columns have a low natural frequency which assures motion isolation from the forces produced by waves. However, long columns require large quantities of material which add to the cost, weight, transportation, and erection problems. A more efficient float

design was attempted during this program by combining the advantages of relatively low natural frequency together with attenuated wave exciting forces. This float or column design has been approached by engineering the float shape to produce appropriate virtual mass and damping.

2 - 7. The contract to conduct this program was originally scheduled to be conducted in three phases;i.e. Design Study, Design Testing and Detail Design. After starting the program according to this plan, several events occurred which required some modifications to the detailed plan for the latter two phases. These changes resulted due to the priority placed on the model tests and the addition of an analysis requested by ARPA.

2 - 8. In Section III of this report, a discussion of the work which was conducted under each of the resulting phases of this program is presented. A more complete analysis may be found in the referenced reports.

2 - 9. Section IV describes a recommended program for future effort in the development of an Expandable Floating Base.

2 - 10. A list of drawings (see page) which were generated during an abbreviated Phase III has been submitted to the government separately in accordance with DD Form 1423, set forth as Exhibit B of the contract.

SECTION III
DISCUSSION OF THE PROGRAM

3 - 1. General.

3 - 2. GAC has conducted a program to investigate the technical feasibility of joining together large expandable structures to form a Floating Island Base. The program to determine this feasibility was originally planned to be conducted in three (3) phases as follows:

Phase I. Design Study - the identification and analysis of pertinent design parameters;

Phase II. Design Testing - the test of candidate materials, components and a dynamic model;

Phase III. Detail Design - final engineering design of a full-size module of the floating island base, based on data obtained in the previous phases.

3 - 3. The initial phase of the program was conducted as planned and consisted of (1) an establishment of the requirements for an island to survive the open ocean environment; (2) the investigation of parameters to be used in the design of an expandable floating base in the ocean environment; and (3) a preliminary design of the floating island as an airplane landing base to show the integration of the parameters investigated. A report to document the results of this effort was submitted upon completion of this phase. (See Reference 2).

3 - 4. In parallel with the completion of Phase I, the Phase II - Design Testing effort was started. Design testing was planned to be conducted on (1) the candidate fabrics of the expandable components, (2) the landing mat surface, (3) the testing of components and (4) the test of an instrumented dynamic model planned for a GFE test facility.

3 - 5. In August of 1970, however, shortly after the program started, GAC was notified that it was not feasible for ONR to provide the test facility as GFE. GAC was instructed to locate a suitable site and arrange for scheduling and conduct of tests. GAC was also notified that no funds were budgeted for such facility.

3 - 6. While limited planning effort in the four (4) areas of the Design Testing program continued, this entire Phase II was evaluated with respect to the results to be expected and needed to proceed with the planned Phase III - Detail Design. The tests planned were also reviewed with respect to the results and conclusions of the Phase I effort.

3 - 7. In addition, a meeting was held in Washington on 14 December 1970, with representatives of ARPA, ONR and GAC. At that time a brief systems study and cost data were requrested to determine the island's worth.

3 - 8. In the review of the aforementioned events, it was determined that the model tests were of primary importance in proving the island concept. In order to complete the basic program including these model tests within the allocated time schedule and funds available,the scope of work for the remaining portion of the contract was changed. This change was accomplished with the approval of the ONR Scientific Officer, by reducing the number and type of tests to be conducted during Phase II and by reducing the magnitude of the Phase III - Detail Design effort.

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3 - 9. The addition of a Systems Analysis program, which was designated as Phase IIa, reduced the magnitude of Phase III to support the effort for other parts of the program.

3 - 10. Phase I - Design Study.

3 - 11. The Phase I program was conducted with three (3) objectives in mind;

a. Establish design requirements
b. Study preliminary design concepts
c. Conduct analytical studies

3 - 12. In order to establish the design requirements, it was necessary to achieve a sound understanding of the conditions which would be compatible with the requirements for an island that could perform a mission and survive in a sea environment. One of the first tasks performed under Phase I was to investigate the technical feasibility of using large expandable structures joined together to form a floating island base. This necessitated a study of pertinent parameters which would affect the design of an Expandable Floating Base. It was also necessary to attempt to establish some realistic conditions and loads with which different design configurations using this type of structure could be evaluated as to their adequacy. Parameters considered included sea conditions (for normal operations and survival conditions), requirements based on intended use, transportability, and assembly time, method ar equipment.

3 - 13. In the study of the preliminary design concepts, the areas investigated included:

a. Vertical Floats - number required, size, spacing, pressure, fabric strength and weight, and bracing required as a function of loads applied.

b. Inflated Plate Structure - thickness, method of fabrication, methods of attaching landing mat, loading conditions.

c. Landing Surface - wheel loads, skin thickness, core thickness, core and skin material, anti-skid surface, joints between sections, sizes of mat, and attachment to inflated plate structure.

d. Auxiliary Equipment - Air inflation systems and water filling systems.

3 - 14. When the analytical studies were conducted, certain structural and motion characteristics were established which were believed to be applicable for starting the parametric studies. The limits or boundaries which were used in the parametric studies include:

a. Fabric strength and stiffness
b. Fabric load factors
c. Vertical float diameters, spacing and bracing
d. Platform height above mean water surface

3 - 15. A summary of parametric boundaries and limits is presented in Table 3-1.

3 - 16. An initial assumption made in establishing design sea conditions was that a temporary base whose mission is the handling of large cargo aircraft need not be usable in all weather conditions. When an acceptable percentage of inoperable time is specified, the sea state corresponding to this time can be established from available statistical data, as suggested in Table 3-2. The base will survive without fatal structural damage at some sea state which is appreciably higher than the inoperable state.

3 - 17. Through the years, seafaring personnel have evolved a system of specifying sea states by number. The essential portions of this system, which is now in use by the U.S. Navy, may be found in Reference 3. As usually defined, a sea state includes a range of wave heights and wave lengths. For analytical purposes, towing

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TABLE 3-1

SUMMARY OF PARAMETRIC STUDY BOUNDARIES AND LIMITS

Fabric Strength		
Inflated Understructure	-	F_{tu} = 1750 lbs/in (Seam strength limitation)
Vertical Floats	-	F_{tu} = 2540 lbs/in (Seamless wrapped structure) (Foldability limitation)
Vertical Float Diameters	-	2 to 10 feet
Vertical Float Spacing	-	6 to 60 feet
Vertical Float Bracing	-	a. Bracing bay depth equals float spacing
		b. Bracing bay depth equals 3/4 float spacing
		c. Bracing bay depth equals 1/2 float spacing
Platform Height Above Mean Water Surface	-	Height equal to half wave height up to 25 feet above mean water surface.

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TABLE 3-2 - SEA STATES AND WAVE HEIGHTS

Sea State	Average Wave Ht. Ft.	Sign. Wave Ht. Ft.	Av. of 1/10 Highest Waves, Ft.	Period of Max. Energy, T, sec	Wave Length of Max Energy $L_d = \frac{g}{2\pi} T^2$, Ft.	Prob. of eq. or Exc. Sea State %	Prob. of Sea State %
0	.05	.08	.10	0.7	2.5	100	0.1
1	0.6	1.0	1.2	3.4	59	99.9	2.9
2	1.4	2.2	2.8	4.3	95	97	18
3	2.9	4.6	5.8	6.5	216	79	24
4	4.3	6.9	8.7	7.7	304	55	25
5	6.4	10	13	8.9	406	30	17.5
6	9.6	15	20	10.5	565	12.5	11.0
7	19	30	38	13.6	948	1.5	1.4
8	31	50	64	17.0	1480	0.1	.09
9	54	87	110	21.0	2260	.01	.01

tank personnel have chosen typical wave heights within each sea state range to represent a specific sea state. Table 3-2 shows the suggested values and gives their corresponding periods and wave lengths of maximum energy as given in Reference 3.

3 - 18. Two additional columns are also given in Table 3-2 the probabilities of the significant waves corresponding to a given sea state are taken from Reference 4. This data is for the North Atlantic and much more favorable probabilities can be shown for other parts of the world's oceans, as is shown by Reference 5.

3 - 19. A review of this table led to the selection of sea state 5 as the design operational condition. The average of the 1/10 highest waves, 13 feet, was used as the design wave height, with the corresponding wave length and period as shown in the table. According to Reference 6, if 10 feet is the significant wave height (sea state 5) a 13 ft wave has a probability of 0.09. The probability of getting a 13 ft wave in sea state 4 is on the order of 0.1%. Neglecting this, and if the probability of exceeding a sea state in which 10 feet is the significant wave height is 30%, then the base is operational in 100 - 30(.09) = 97.3% of all waves in sea states up to 5. In sea state 6, 52.5% of the waves would exceed 13 ft. This amounts to 1.5 + .53 (11) + .09 (17.5) = 8.9% of all waves in all sea states. It follows that, with the 13 ft design wave criterion, the floating base could be operational, statistically speaking, in 91% of the waves encountered in the North Atlantic. Since the larger waves have generally longer periods, the operational times as a percentage of time on station would be somewhat smaller.

3 - 20. Several methods of determining the manner in which the energy of waves in an irregular sea state is distributed over a frequency range are given in Reference 7. Another formulation of standard wave spectra, by Pierson and Moskowitz, is also available in Reference 8. Statistical data on recurrence of high winds is available but mainly for coastal areas (see Reference 9). Wind may be important to the design of service buildings, tie-down structures or the orientation of the runway, but it is not a significant

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factor as far as the feasibility of the floating base is concerned.

3 - 21. Other design requirements are determined by the aircraft which use the Expandable Floating Base. For such a mission, the design must:

a. Provide adequate strength to carry the aircraft wheel loadings.

b. Provide adequate runway length and parking area.

c. Limit the heaving motion of the deck to magnitudes compatible with the aircraft's landing gear capability.

3 - 22. Table 3-3 shows basic data for several transport aircraft.

3 - 23. The pertinent load factors for which aircraft are designed, taken from Refs. 10 and 11, are given in Table 3-4. The same factors are applicable to the design of the landing deck and its supporting structure.

3 - 24. Design requirements must include considerations for level landings with braking and side loads, wheel spin up and spring back, braked roll, one wheel landing, takeoff run, rebound landing, turning, pivoting, taxiing, jacking, etc. It then becomes necessary in order to define a general specification for the deck heave to consider "worst case" landing and rollout conditions and their probability of occurrence in combination with other conditions by rationalization and experience.

3 - 25. Three "worst case" ground load conditions which are most obviously affected by deck motion are;

a. Airplane main wheels contacting deck on up-slope of wave with a vertical contact velocity of 10 fps (design requirements for commercial airplane "Oleo" strut and tire combinations).

b. Landing roll-out in trough of deck wave.

c. Airplane grazes crest on landing and free falls to trough.

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TABLE 3-3 - AIRCRAFT DATA

Aircraft	Size		Weight	Wheels				Distance	
	Length (Feet)	Span (Feet)	Max. T.O. (Pounds)	Base (Feet)	Track (Feet)	Main Size	No.	Ldg. (Feet)	T.O. (Feet)
VC-140B	60	54	42,000	20-1/2	12-1/4	26x6.6	4	2450	3740
C-9A	125	93	114,000	56	16-1/2	40x14	4	4800	8000
C-130E	98	132	155,000	32	14	56x20	4	2100	3800
C-141	145	160	316,000	53	17-1/2	44x16	8	2200	4000
C-5A	247	222	764,000	73	36	49x17	24	2300	7300

TABLE 3-4 - AIRCRAFT LOAD FACTORS

Airplanes (Ref. 10)

Condition	n (limit) (vertical)	n (limit) (horizontal)	Remarks
Taxiing	2.0*	- -	- -
Braking	1.0	0.8	Based on design gross weight or 1.2 times landing weight

Helicopters

Braked Roll	1.33	1.06	(Ref. 11 sections 27.493 and 27.497)

*This factor was for rough fields. A factor of 1.5 has been assumed adequate for the Floating Base.

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3 - 26. Whether special provisions need be made for holding station depends on the requirements of the mission and the specific geographical position with regard to ocean currents. Therefore, an investigation of station keeping becomes another design requirement, as does the study of the packageability and portability of the Floating Base.

3 - 27. Cargo aircraft considered for transporting floating base components are listed in Table 3-5 (data from Reference 12). General railroad specifications, highway load dimensions, and surface ship capabilities also need to be considered.

3 - 28. Preliminary design concepts which were studied included the investigation of modular units constructed of an air inflated plate on which was placed a surface layer of adhesive bonded sandwich panels with integral bonded edge members to serve as the landing mat (see Figure 2). The vertical floats were cylinders made of expandable structure, each float containing both air and water.

3 - 29. Variations of this concept were added during the Phase I portion of this program thereby providing other configurations for study, one of which included the elimination of the inflated plate and increasing the thickness of the sandwich panel continuous plate (see Figure 3).

3 - 30. Various planforms for the sandwich panel landing mat were also considered (see Figure 4) and the one which most unequivocally makes possible a reduction in bending moments is the triangular shape, which therefore will yield minimum panel thickness.

3 - 31. Another variation of the original concept utilized two or more inflated plates with internal shear webs oriented at right angles to each other (see Figure 5). However, the one feature which was common to all configurations was the vertical cylindrical floats of expandable fabric material and the brace cable arrangements between these columns to add shear capabilities to the island surface as well as to provide column support.

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TABLE 3-5 - AIRCRAFT CARGO COMPARTMENT DATA

Aircraft	Cargo Comp.			Door		Payload	Range	Distributed
	L(in)	W(in)	H(in)	W(in)	H(in)	(lb)	(N.Mi.)	Load (psf)
C-5A	1453	228	162	228	162	265,000	2950	
C-141A	840	123	109	123	109	62,000	4000	300
C-130 A/B/D/E	492	123.25	109	115	104.8	37,000	2900	
C-133 A/B	1168	141.6	144	114	100	95,000	1600	300

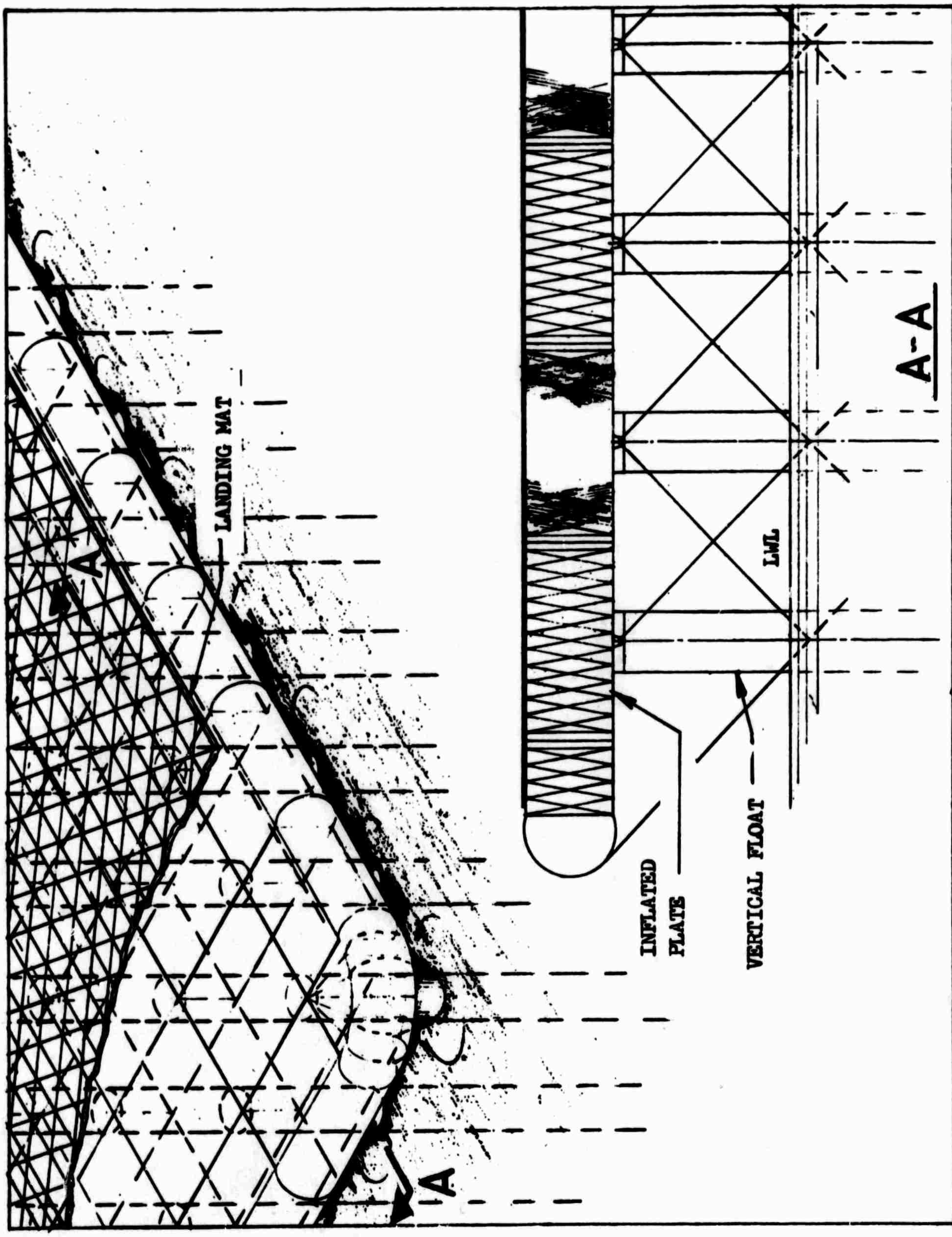

Figure 2. Expandable Floating Base - Configuration I

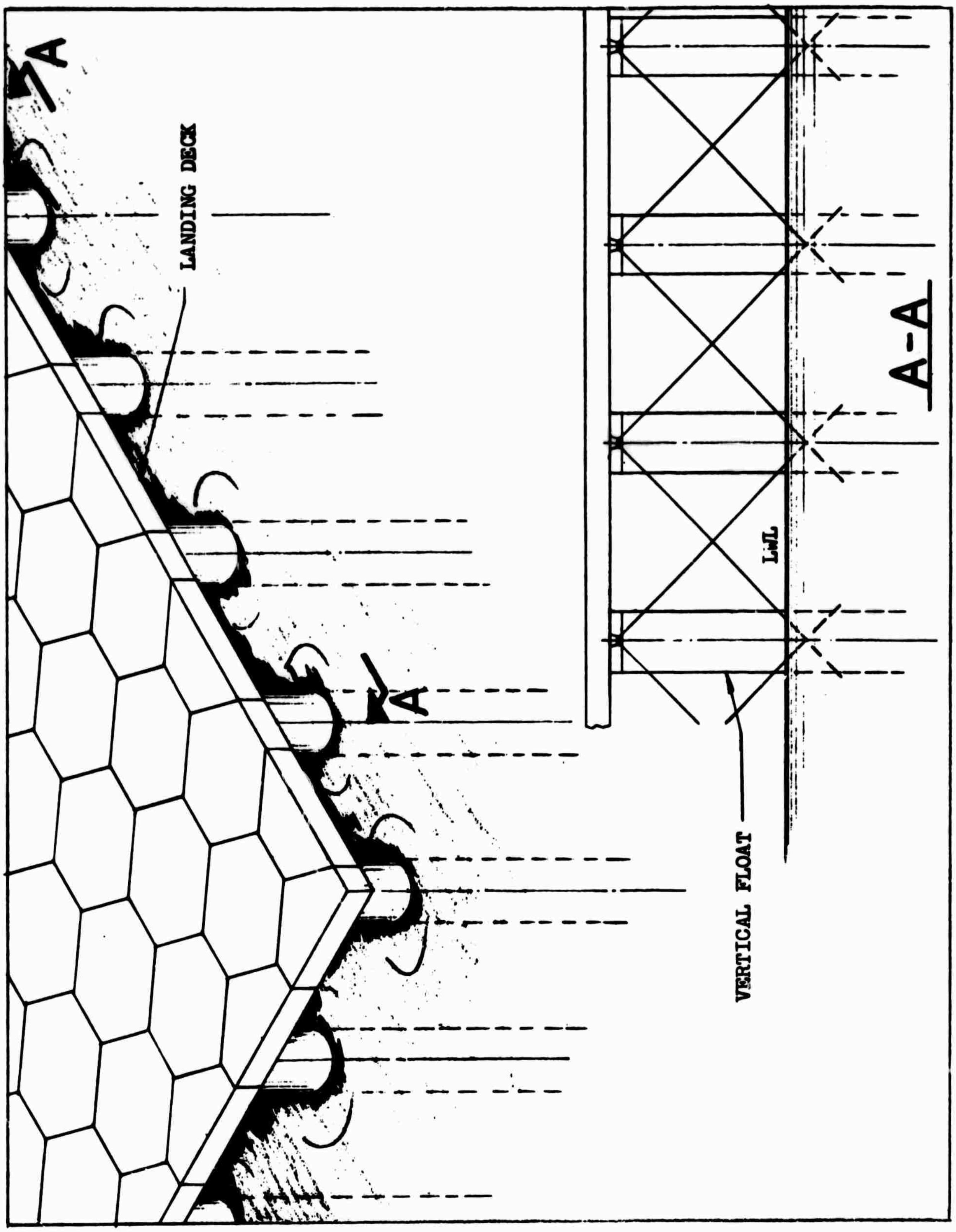

Figure 3. Expandable Floating Base - Configuration III

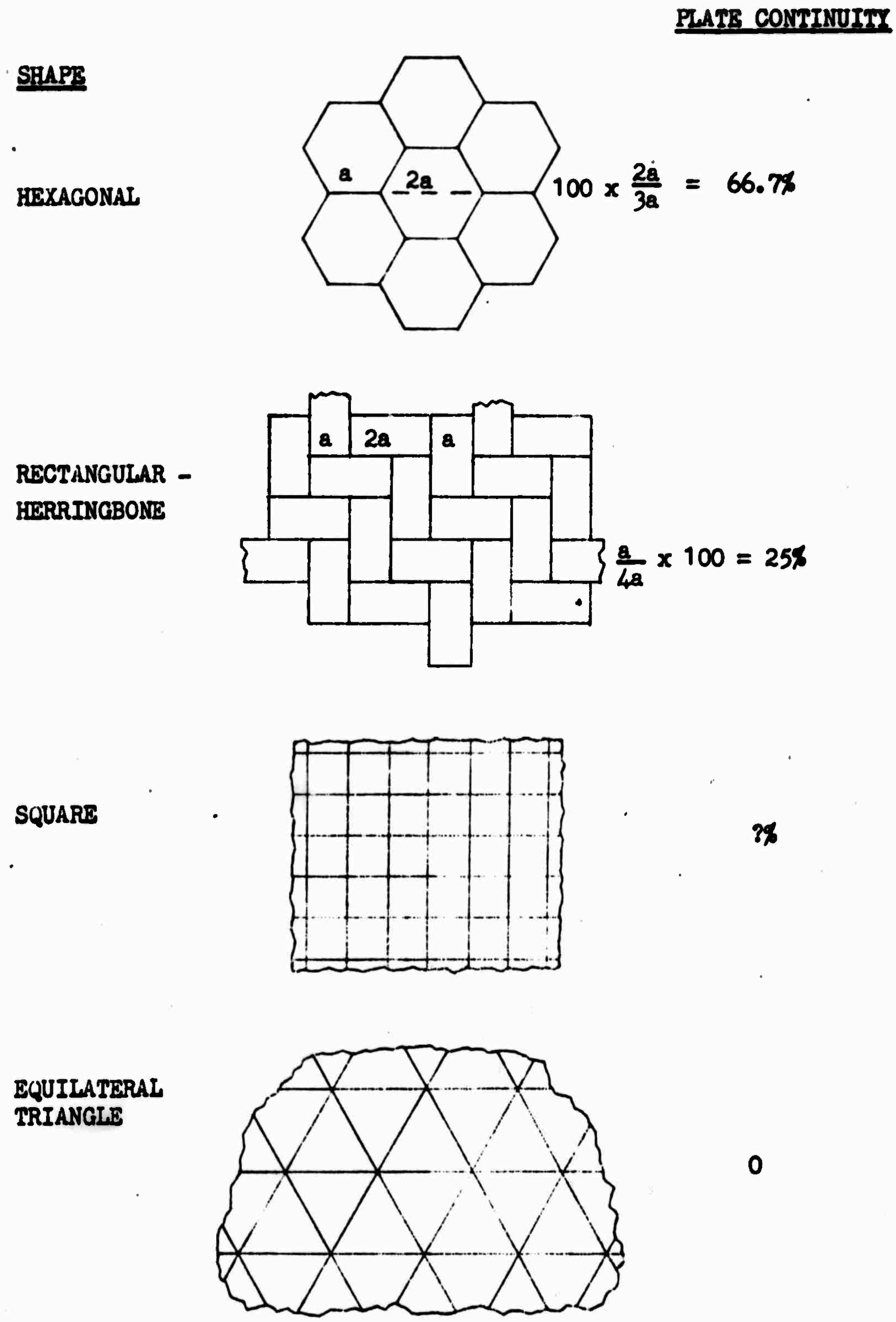

Figure 4. Comparison of Bending Efficiency for Various Panel Configurations

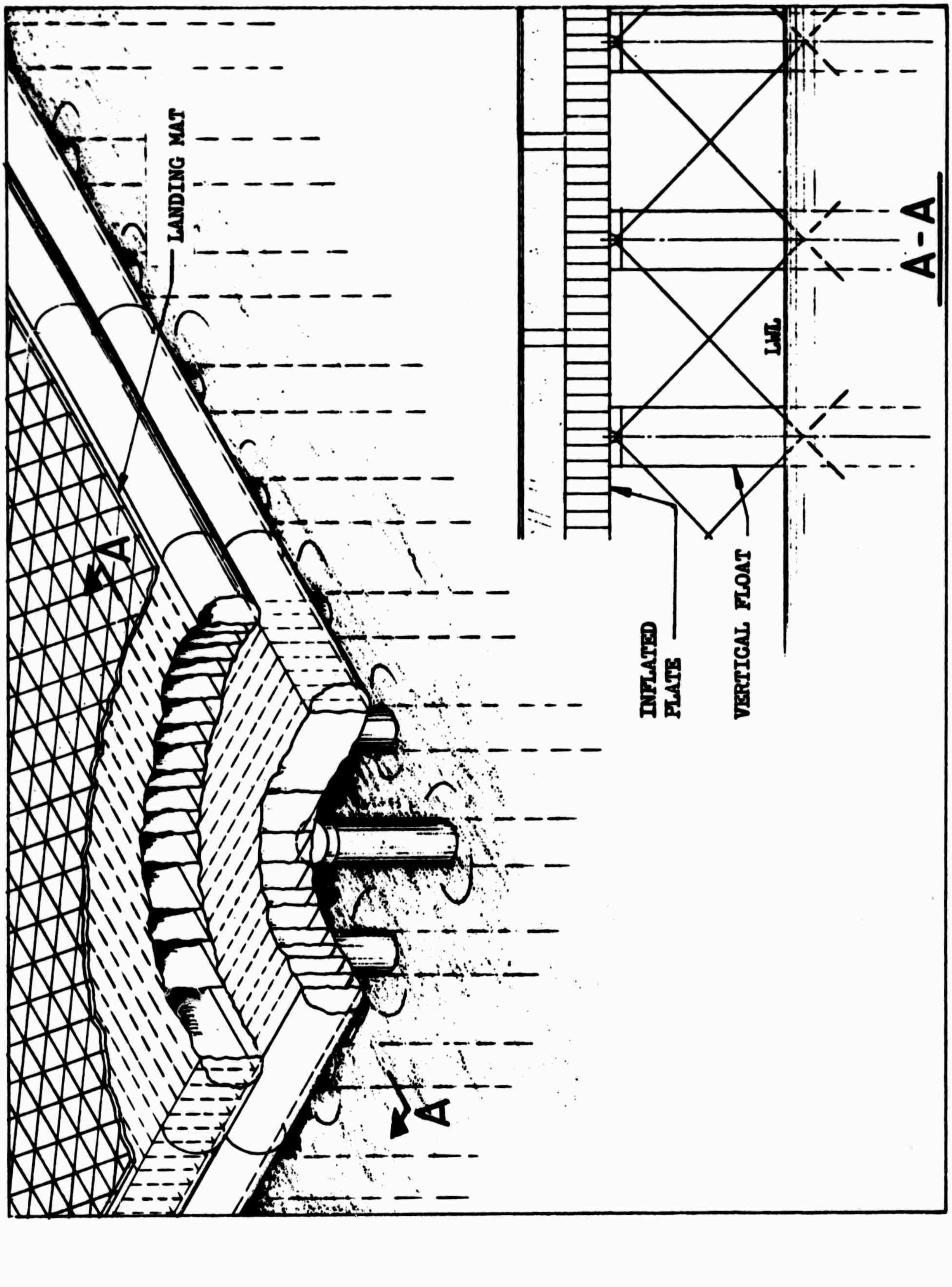

Figure 5. Expandable Floating Base - Configuration II

3 - 32. As previously stated, certain parametric study boundaries and limits were established in the analytical studies (summarized in Table 3-1. Inflated plate fabric strength and stiffness were studied to determine the number of layers of cloth to be plied together. Foldability and seam strength are major factors in this and the seam strength is strongly dependent on temperature. 1750 lbs/in was originally assumed as a limiting strength for fabric seams in the floating base inflated plate.

3 - 33. Using currently available material, a four-ply float could have a strength of 30,500 lbs/ft in the axial and hoop directions and still be foldable. Thus, floats made of four plies of polyester tire cord were chosen as the limiting fabric strength based on foldability.

3 - 34. Values for Dacron were used throughout this study in considering fabric stiffness, however, the effects of higher stiffness for the floats or columns was also included.

3 - 35. Fabric limit loads which are defined as the maximum load the structure is expected to encounter, are multiplied by the factors listed in Table 3-6 to obtain the structural design loads used during the Phase I - Design Study.

3 - 36. For this study the vertical float diameters considered were bounded by a minimum diameter of two (2) feet and a maximum diameter of ten (10) feet. These considerations of diameters permitted a variation of float pressures from 1,000 to 7,000 psf. This range of values was believed to encompass practical design pressures and diameters for this program.

3 - 37. In considering vertical float spacing, since the floats support the platform, the maximum spacing distance between floats approaches a limit for constant platform loading and a given structural condition. On the other hand, certain lateral forces on the floats due to wave action increase as the float spacing

TABLE 3-6

STRUCTURAL DESIGN LOAD FACTORS

Loads	Operational Yield	Operational Ultimate	Survival Yield	Survival Ultimate
Type of Structure				
Fabric				
Wrinkling	1.0	- -	- -	- -
Buckling or Collapse	- -	1.75	- -	1.0*
Tension	- -	**	- -	**
Cables	- -	2.0	- -	1.25
Sandwich Panels (Mats)				
Primary	1.5	2.0	- -	1.0
Secondary	1.0	1.5	- -	1.0
Other Metal	1.0	2.0	- -	1.0

* Buckling or collapse of certain members may be permitted if it contributes to, or does not impair, survivability of the base and its occupants in severe weather.

** The strength reduction factor as used provides adequate margins of safety.

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decreases, so that there is a desirable minimum spacing. To limit this study to a reasonable number of solutions, a relationship between float diameter and float spacing was established. This relationship, b = mD, was limited to m values of 3, 4, 5, and 6.

3 - 38. In the parametric study, it was necessary to use common systems of bracing for the floats to permit a comparison of the data generated. As a result, the determination of the optimum bracing for a specific combination of float diameters, float spacing and platform structure was not attempted. An optimum system might consist of compression members and cables with a varying space with depth. Such consideration was held in abeyance until a specific design requirement was established.

3 - 39. Structural Analysis.

3 - 40. Assuming that the floating base would be an aircraft landing platform, the major structural loadings on the platform result from:

1) the aircraft landing on it and
2) the action of the sea waves on it.

3 - 41. Other loadings are:

1) Dead Loads
    a) Structural Weight
    b) Snow or Ice Loads
    c) Mission Support Equipment Weight or Superstructure Weight
2) Buoyancy Forces
3) Wave Forces
    a) Vertical
    b) Horizontal

3 - 42. The distribution of the load among the columns is complicated by the possible variations in:

1) The position of the aircraft on the platform.
2) The spacing and size of the columns.
3) The depth to which the columns extend below the surface of the water.
4) Interaction of the inflated structure and the landing surface.
5) The state of the sea.

3 - 43. To eliminate confusing detail, the problem was reduced to treating the platform as a plate on an elastic foundation. Since the vertical displacement of each column is proportional to its load, and if the columns are cylindrical and of equal size and spacing, their support can be replaced by assuming a uniform elastic foundation which corresponds to the buoyant force from a fluid having a density

$$\rho' = \rho \frac{A_c}{b^2}$$

As for the plate, it was at first assumed that the bonded sandwich panels used for landing mats served only to distribute the load concentrated under the wheels of taxiing, landing, or parked aircraft, and that the inflated plate served to spread the load to the foundation. (With this consideration, determination of column loads becomes a detail without importance for the deck analysis since the stress concentrations in the plate from the column loads are expected to be smaller than those from the wheel loads).

3 - 44. Initially it was assumed that the platform was floating in calm water and attention was confined to the basic aircraft loads.

3 - 45. Because relatively complete information on the C-130 airplane was available, and since it is a representative cargo aircraft, this aircraft was chosen for the initial studies. The plan view of this aircraft is shown in Figure 6.

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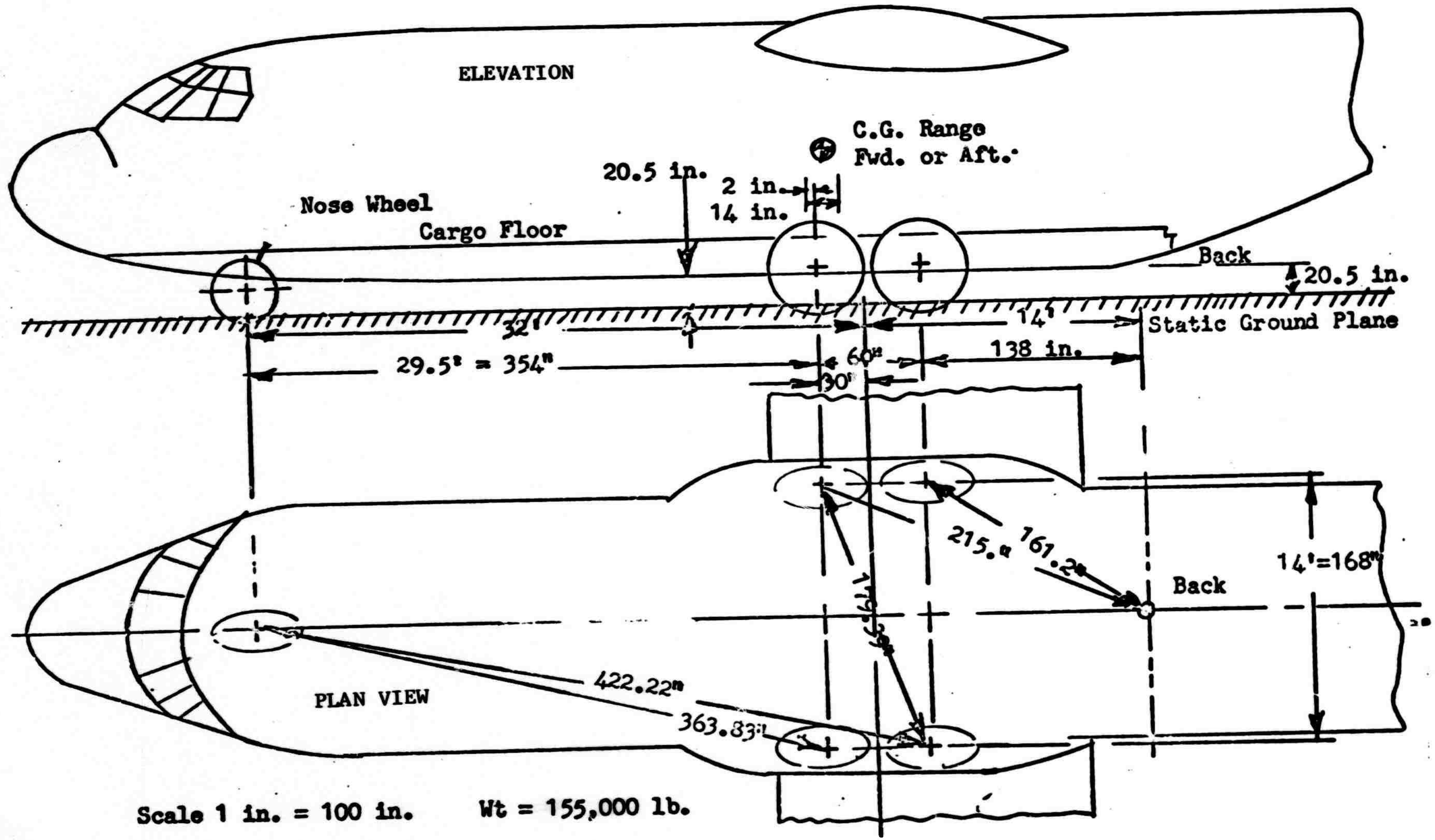


Figure 6. C-130 Static Weight Elevation and Wheel Geometry

3 - 46. At the time the analysis in Phase I was conducted, the concept of the floating base was one of an inflated plate with a superimposed decking of aircraft landing mats, which were comparable to those used at advance-base military landing fields, supported on an array of ballasted, vertical cylindrical floats. The four configurations previously described were analyzed during Phase I, during which time a variety of structural problems associated with the inflated plate designs were investigated and solved. These problems were mentioned in the introduction and the details of the analyses are given in Reference 2.

3 - 47. The analysis of configuration III is summarized here since it was the configuration assumed for the systems analysis, Phase IIa.

3 - 48. Capability of configuration III.

3 - 49. General. Configuration III (See Figure 1) dispenses entirely with the inflated plate. The bonded sandwich panels carry the load to the columns and beyond. For maximum bending efficiency, hexagonal panels should be used; these have a theoretical efficiency of 66.7%, as discussed earlier.

3 - 50. The allowable skin stress has been taken as 17,000 psi after a factor of 2.0 has been applied to the compression yield strength, and an allowable load P is plotted in Figure 7 along with the bending moment and h_s. Figure 8 is a cross-plot of this information for the specific case of a square loaded area 40.4 inches on a side, which is roughly equivalent to two C-130 wheel footprint areas. Figure 8 also shows the elastic-foundation solution, which happens to be for an 11.4-inch radius loaded circle and so is not strictly comparable.

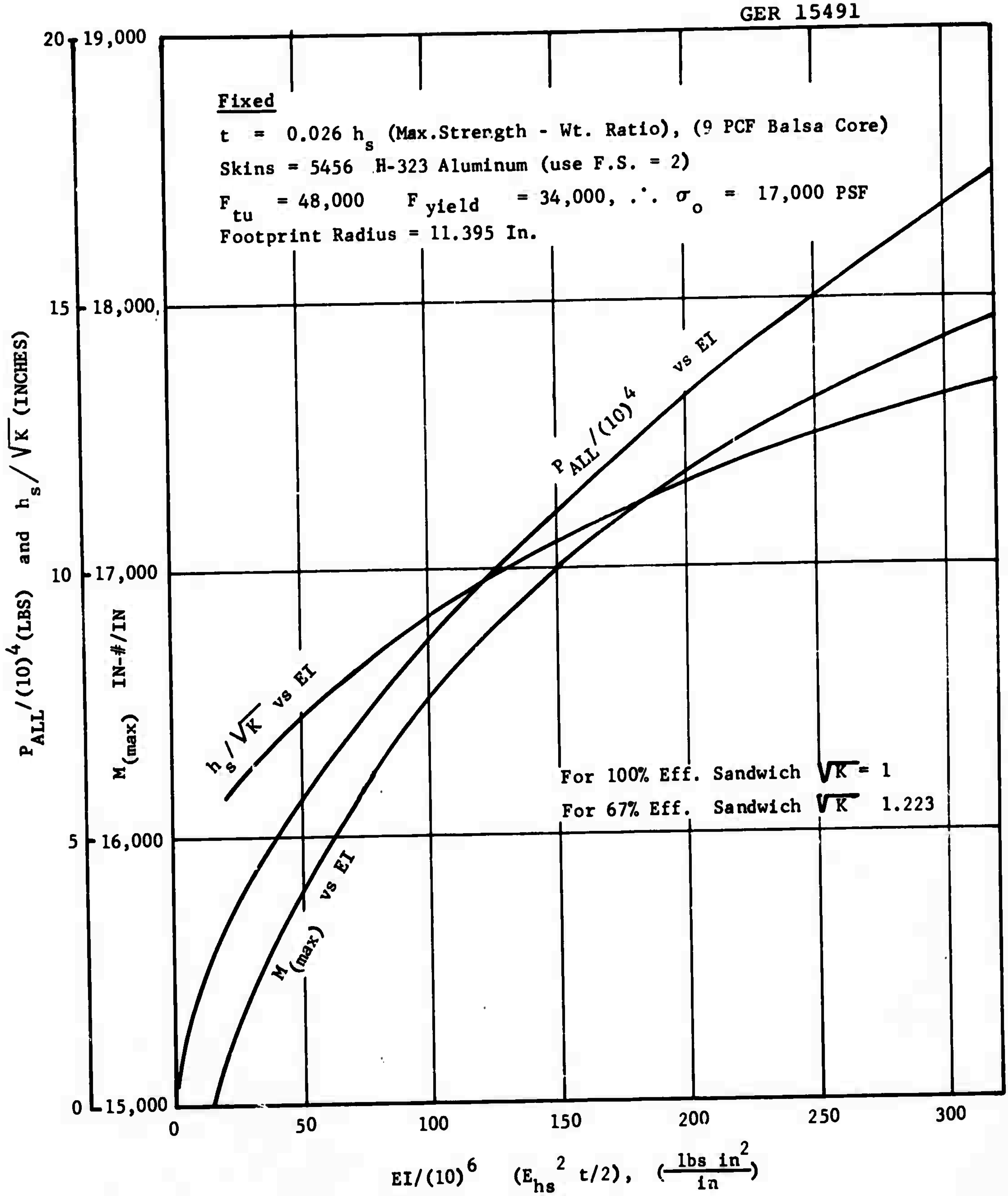


Figure 7. All Sandwich Construction - Elastic Foundation Relationships

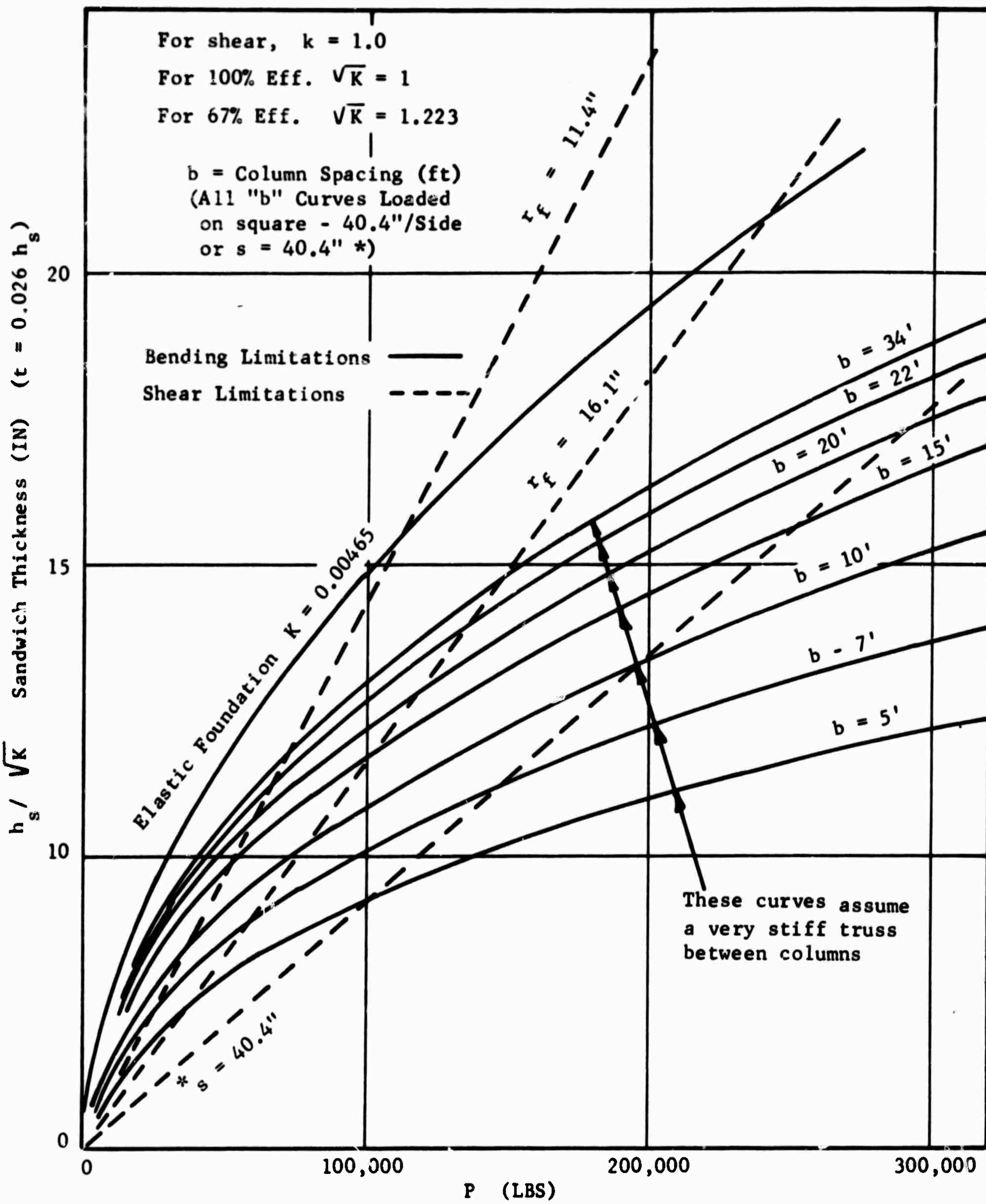


Figure 8. Configuration III - Sandwich Thickness vs Load

3 - 51. The shear capability of the all-bonded sandwich is independent of the column spacing but depends on the footprint perimeter. Lines for three different footprints are shown in Figure 8, based on a safety factor of 2.0 and a balsa shear strength of 300 psi.

3 - 52. The envelope describing possible combinations of load, column spacing, footprint, and sandwich thickness is bounded by the bending curves on the left and by the shear curves on the right.

3 - 53. Staggered Columns. For Configuration III, which uses hexagonal panels, it is desirable to have the columns at the center of the panels, which requires a staggered column spacing. The results already obtained can be adapted to such an arrangement by letting the radius R = .577d [where d is the distance between columns rather than between rows] instead of .707d as for a square arrangement. The distance between rows is .866d if the columns are equidistant from one another.

3 - 54. As an approximation, the curve of Figure 8 is used for staggered column spacing by taking b as .866d. This is somewhat more conservative than assuming an effective $b = \frac{.577}{.707}$ d, since staggering the columns reduces bending moments in the platform.

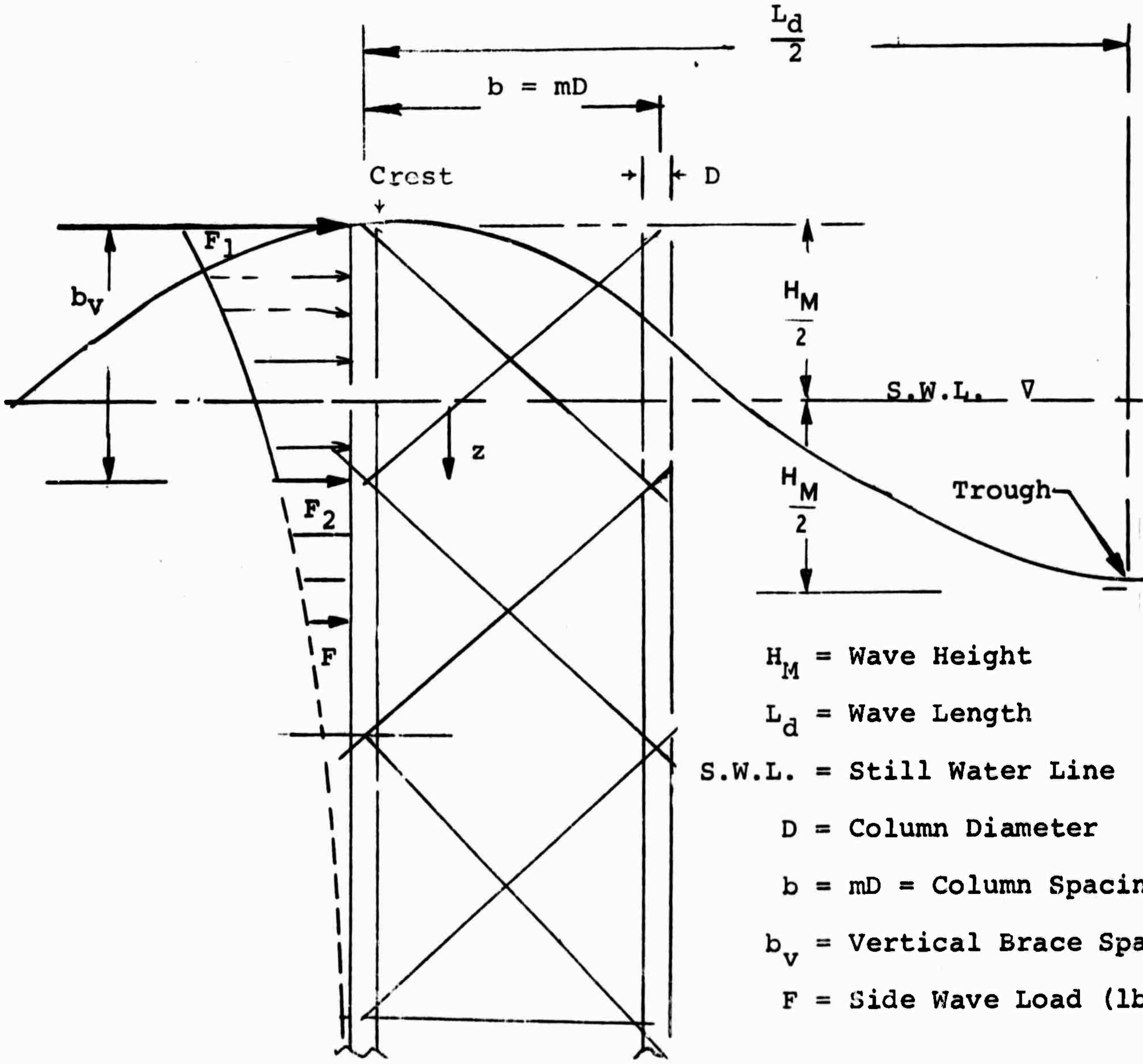
3 - 55. Vertical Floats

3 - 56. General. The loads on the vertical floats, or columns, are due in part to loads from the platform but more importantly from wave action. Wave forces may be both horizontal and vertical, and are an exponentially decreasing function of the depth below the still water level. The length of the floats is determined by the permissible motion of the platform and by the dynamic response of the entire structure to the critical wave spectral densities. The latter cannot be known initially, hence the column length is not known. It is certain, however, that the columns will have to be braced near the top to make them act effectively as cantilevers,

and it is likely that bracing may have to extend to a considerable depth, both to minimize bending and to reduce the Euler buckling length. The top section or bay will be most severely loaded, since it must resist the side force from a surface wave, and also must carry the sum of all vertical loads, including wave forces on the bottom of the column and the vertical reactions of the diagonal bracing. For preliminary study, therefore, only the top bay is analyzed.

3 - 57. Float design is also governed by the variation in the differential pressure between the inside and outside of the inflated columns, which are assumed to be fabric cylinders.

3 - 58. Beam-Column Analysis. The column side loads due to a wave action are shown in Figure 9. If the top bay is conservatively assumed to be simply supported at each end, the resulting free body is shown in Figure 10.



H_M = Wave Height

L_d = Wave Length

S.W.L. = Still Water Line

D = Column Diameter

b = mD = Column Spacing

b_v = Vertical Brace Spacing

F = Side Wave Load (lb/ft)

FIGURE 9 - COLUMN RELATIONSHIPS

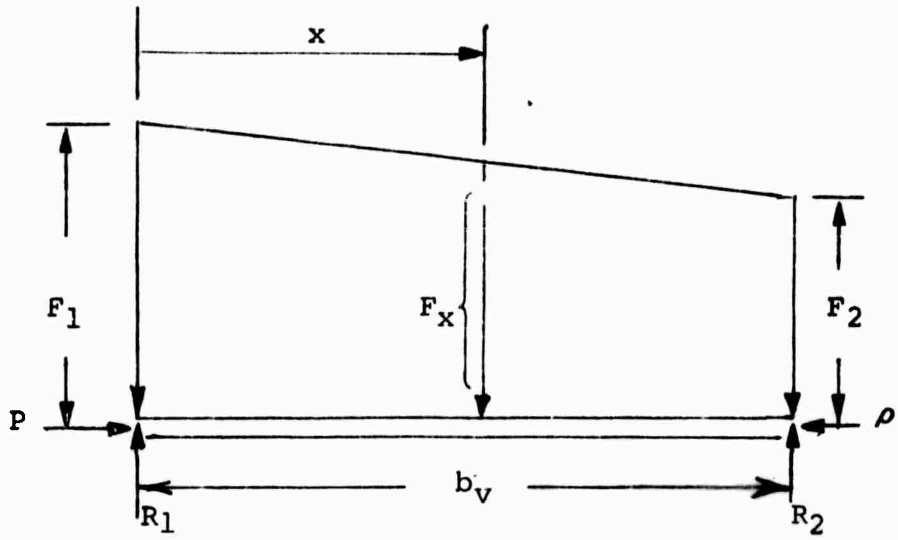


FIGURE 10 - FREE BODY OF COLUMN TOP BAY

3 - 59. The varying side load, F_x, due to wave action drag and inertia on the column is:

$$F_x = \kappa_1 e^{-2kx} + \kappa_2 e^{-kx}$$

where,

$$\kappa_1 = \frac{1}{2} k\rho D \left(\frac{H_M}{2}\right)^2 C_D$$

and

$$\kappa_2 = \frac{\pi}{4} k\rho D^2 \left(\frac{H_M}{2}\right)^2 C_M$$

are coefficients that give velocity and inertial drag components respectively.

3 - 60. To simplify the calculations a trapezoidal distribution between reactions R_1 and R_2 was assumed. The reaction R_1 is

$$R_1 = \frac{b_v}{6} [2 F_1 + F_2]$$

The maximum beam moment, M_{MB}, is found approximately by assuming a uniform load distribution between reactions R_1 and R_2. The maximum moment is

$$M_{MB} = \frac{b_v^2}{16} [F_1 + F_2]$$

3 - 61. The axial load in the top bay is a direct function of the total side load, and the vertical bracing angle. The exponential equation for F_x indicates that the majority of the total side load is in the upper part of a long column. Therefore a close approximation for the total side load on any column is:

$$\Sigma R = \int_0^\infty F_x \, dx$$

$$\text{or} \quad R = \frac{K_1}{2k} + \frac{K_2}{k}$$

Therefore the axial load, P, in the top bay of the column is

$$P = [\Sigma R - R_1] \frac{b_v}{b}$$

3 - 62. The beam column moment, M_{max}, is approximately

$$M_{max} = \frac{M_{MB}}{1 - P/P_E}$$

where:

$$P_E = \frac{\pi^2 EI}{L^2} \quad \text{[for pinned ends]}$$

$$I = \frac{\pi D^3}{8} \quad \text{and } L = b_v$$

3 - 63. Still Water Hoop Pressures Stress [Hoop Tension]. The column stress and pressure are are shown in Figure 11.

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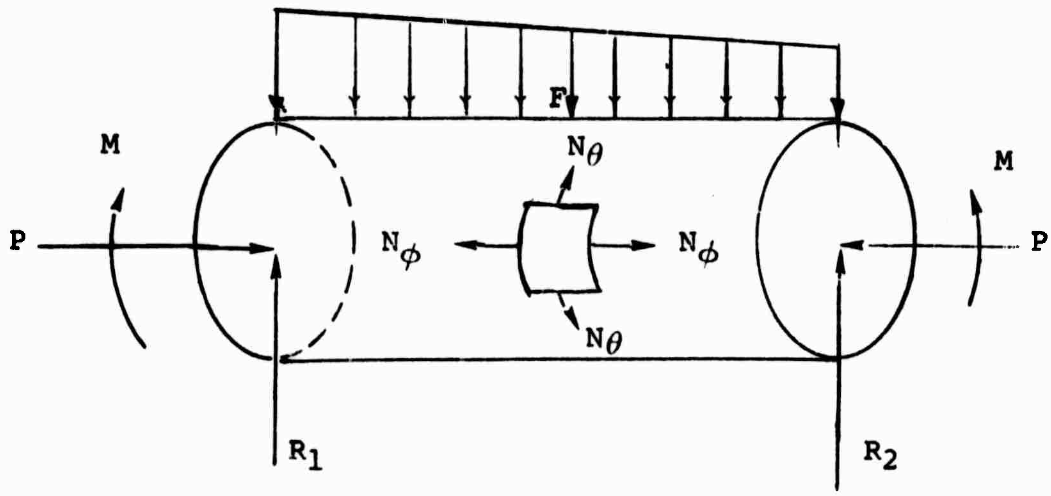

FIGURE 11 - COLUMN LOADS AND STRESSES

$$N_\theta = \frac{pD}{2}$$

$$N_\phi = \frac{pD}{4}$$

Therefore, the hoop stress, N_ϕ, is the greater of the two, and the resulting pressure p_{HT}, as determined by hoop tension is

$$p_{HT} = \frac{2\ N_\theta}{D} = \frac{2\ F_{tu}}{D\ (F.S.)_p} = \frac{2\ F_{tu}}{5D}$$

where:

$$(F.S.)_p = 5$$

3 - 64. Combined Axial Stresses. Axial tension [A T]

$$N_\phi = \left[\frac{p_{AT}\ D}{4} + \frac{M_{MAX} \times D/2}{\frac{\pi\ D^3}{8}} - \frac{p}{\pi D}\right] = \frac{F_{tu}}{(F.S.)_p}$$

$$p_{AT} = \frac{4}{D}\left[\frac{F_{tu}}{5} - \frac{4\ M_{Max}}{\pi\ D^2} + \frac{p}{\pi D}\right]$$

3 - 65. Axial Compression [A C]

$$N_\phi = \frac{p_{AC} D}{4} - \frac{4 M_{Max}}{\pi D^2} - \frac{1.75 p}{\pi D} = 0$$

$$p_{AC} = \frac{4}{D}\left[\frac{4 M_{Max}}{\pi D^2} + \frac{1.75 p}{\pi D}\right]$$

3 - 66. In the equation above, the term involving the axial load P has been multiplied by 1.75 because it represents an ultimate collapse load. The moment M is a function of P, but for simplicity in preliminary analysis it was assumed on the basis of similar work that the collapse moment is approximately 1.75 times the wrinkling moment.

3 - 67. Axial Load Only. For short columns when Euler buckling is not critical the maximum axial load a column can take, P_A, is equal to the column inflation pressure, p_D, times the column area, $\left(\frac{D^2 \pi}{4}\right)$, divided by a factor of safety against collapse, $(FS)_B = 1.75$.

Or $$P_A = \frac{p_D \times D^2 \pi}{(FS)_B \; 4}$$

p_D is usually based upon the fabric limited hoop stress, $p_{HT} = \frac{2F_{tu}}{5D}$. However, for the few cases of a column in a trough with $z < \frac{H_M}{2}$ this p_D is reduced.

3 - 68. The still water displacement depth z is a function of the distributed platform load [w lb/ft^2], the column diameter, and column spacing. For this work the total live plus dead load was taken as

$$w = 50 \text{ lbs/ft}^2$$

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3 - 69. Parametric Analysis. The following values were fixed:

ρ = 64.0 lb/ft^3
w = 50.0 lb/ft^2
F_{tu} = 30,500 lb/ft
E = $(5 \times F_{tu})$ = 152,000 lb/ft (polyester)
k = $(2\pi/L_d)$ = 0.012/ft
n_p = Strength reduction factor for pressure = 5
n_w = Strength reduction factor for transient wave action = 4
C_D = Velocity Drag Coefficient = 1.05
C_M = Inertial Drag Coefficient = 1.40

The following variables were considered:

H_M (Wave Height) = 20, 30, 40, 50 (ft)
m (Col. Spac = b = m D) = 3, 4, 5, 6
D (Col. Dia.) = 2, 4, 6, 8, 10 (ft)
b_v (Vert. Col. Brace Spacing) = mD, .75 mD, .5 mD

3 - 70. Equations were programmed for the IBM 360 computer and solved for the 240 combinations of variables listed above and 80 for each of the three types of vertical brace spacings. Figure 12, which represents the results of the parametric work in this section, demonstrates the effects of this trade off in design pressures. This design curve, is a plot of allowable wave height as a function of column diameter and spacing.

3 - 71. Figures 13, 14 and 15 are cross plots of the allowable pressure p_{HT} of p_{TR} and the wrinkling pressure p_{AC} vs column diameter for the three vertical brace spacings.

3 - 72. Stability Analysis.

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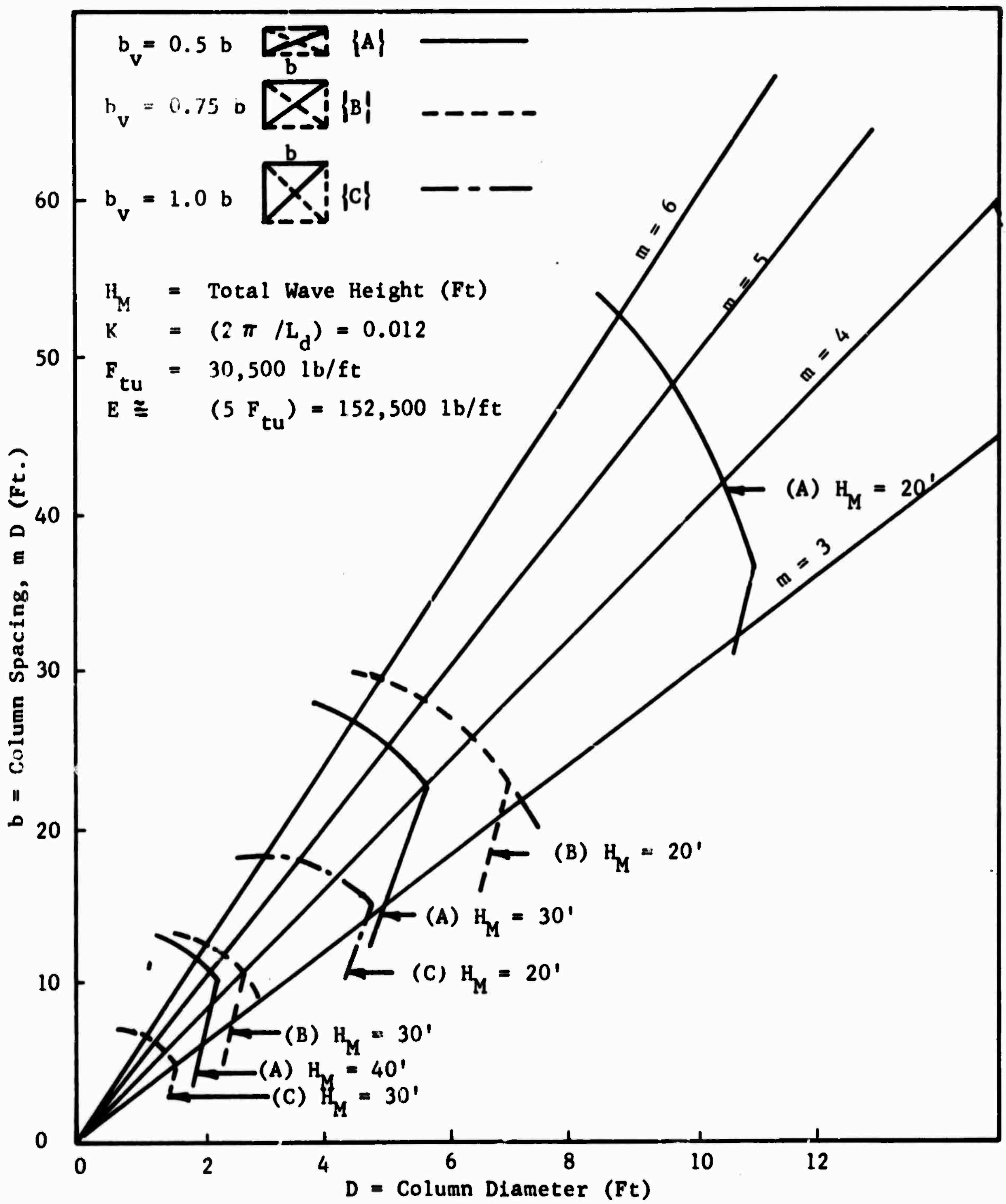
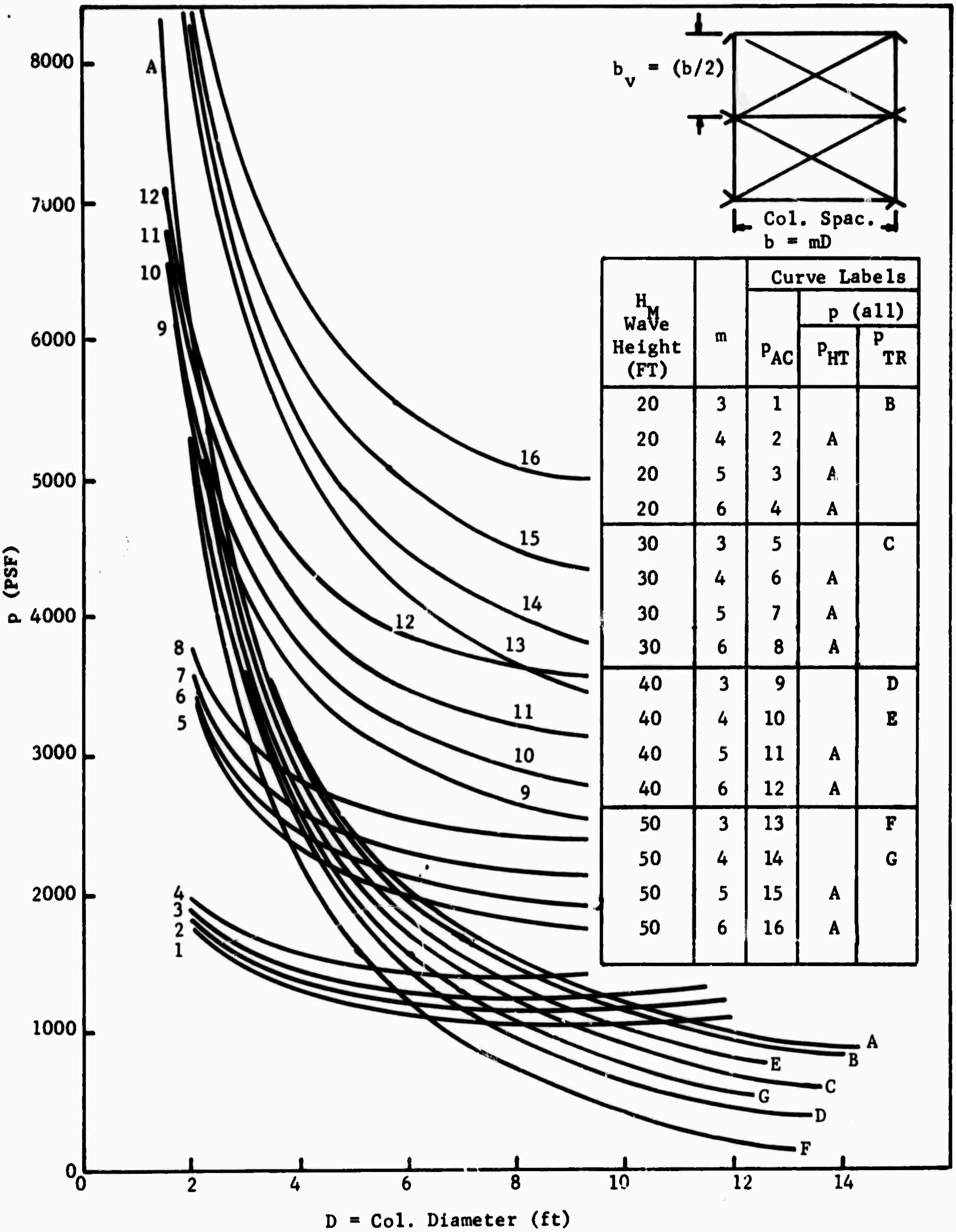
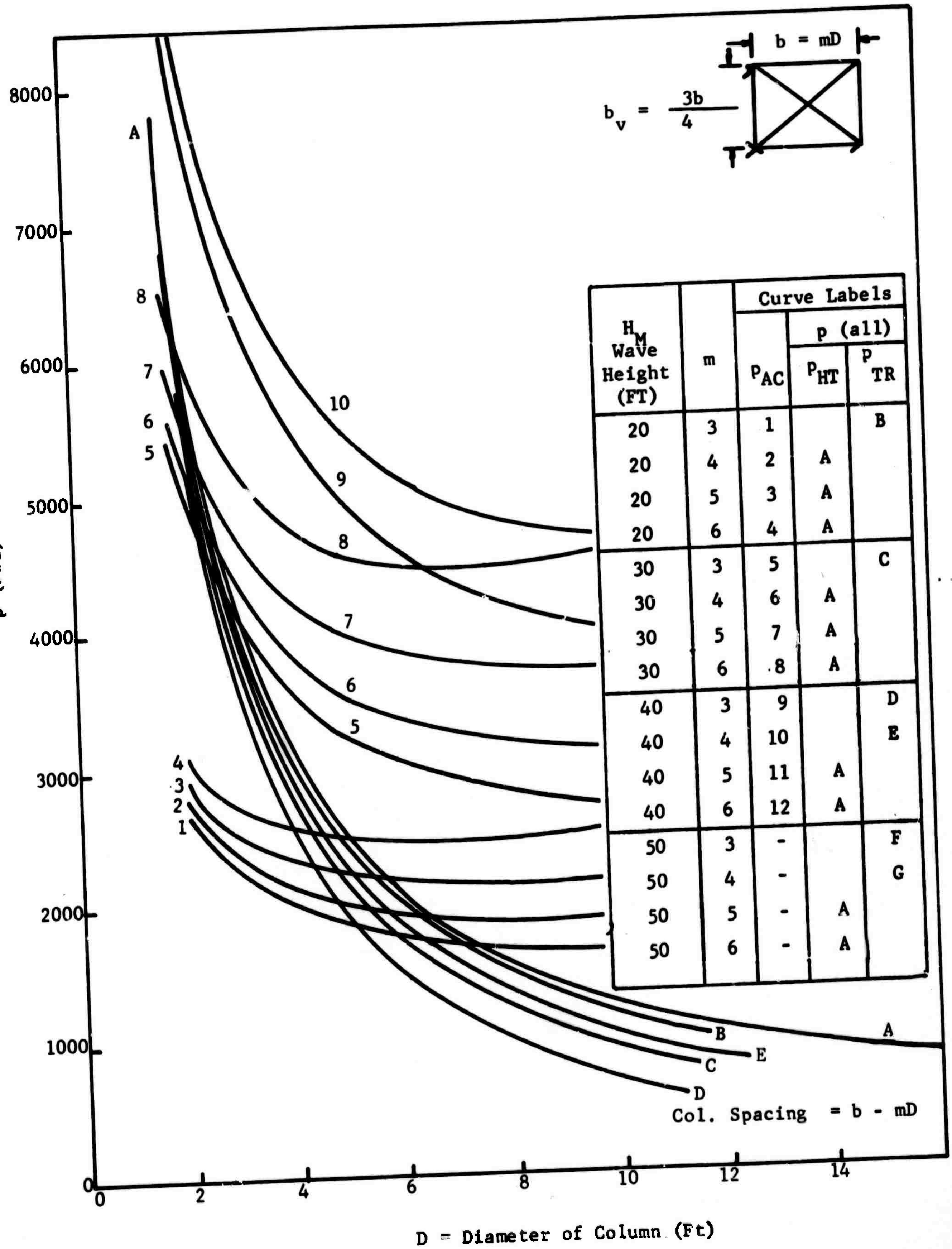


Figure 12. Design Curve - Allowable Wave Height for Variable Col. Dia.'s and Spacing



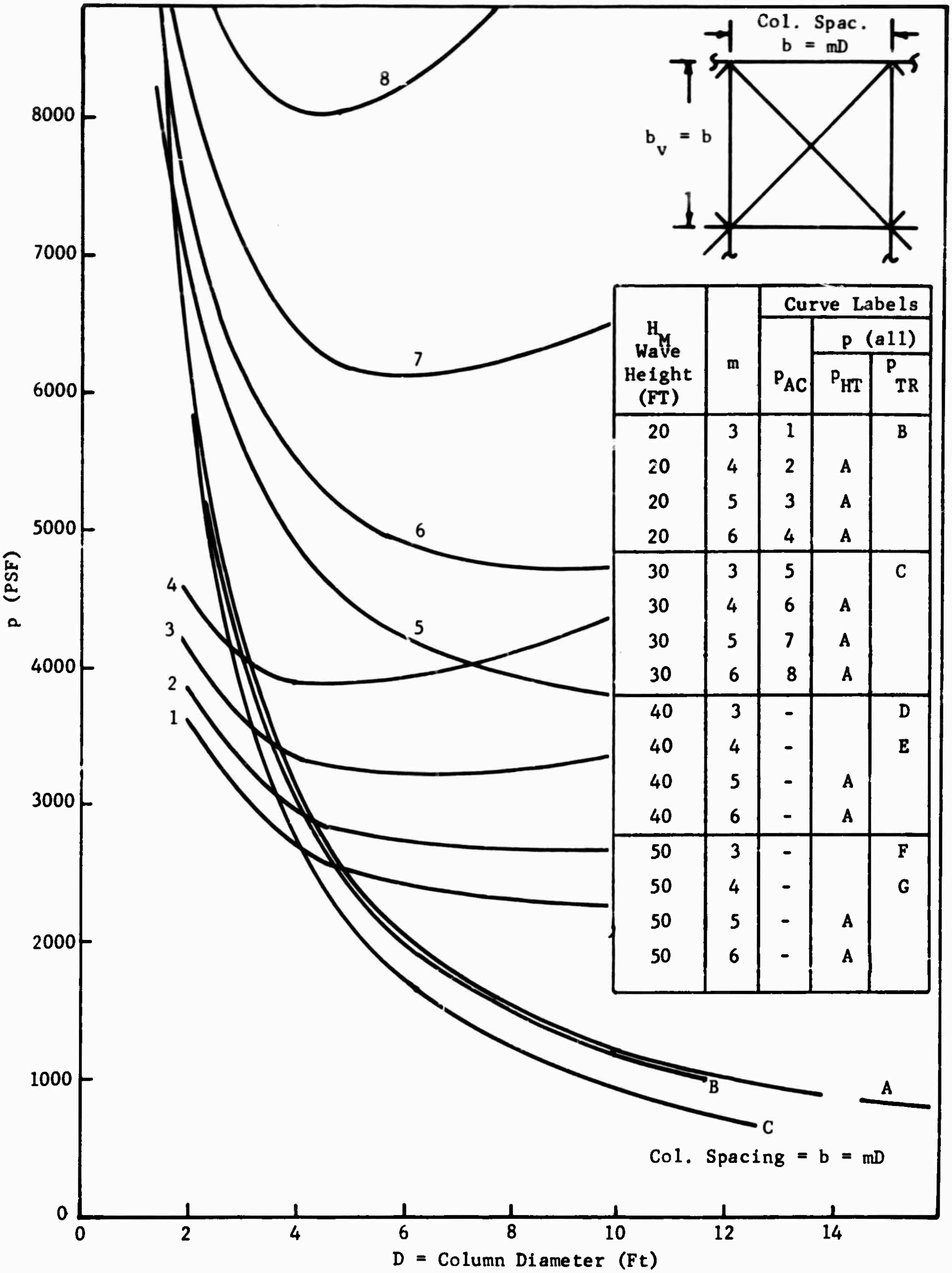
H_M Wave Height (FT)	m	Curve Labels		
			p (all)	
		p_{AC}	p_{HT}	p_{TR}
20	3	1		B
20	4	2	A	
20	5	3	A	
20	6	4	A	
30	3	5		C
30	4	6	A	
30	5	7	A	
30	6	8	A	
40	3	9		D
40	4	10		E
40	5	11	A	
40	6	12	A	
50	3	13		F
50	4	14		G
50	5	15	A	
50	6	16	A	

Figure 13. Column Diameter, D, vs p's for b_v = 0.5 b = 0.5 mD



H_M Wave Height (FT)	m	Curve Labels		
			p (all)	
		p_{AC}	p_{HT}	p_{TR}
20	3	1		B
20	4	2	A	
20	5	3	A	
20	6	4	A	
30	3	5		C
30	4	6	A	
30	5	7	A	
30	6	8	A	
40	3	9		D
40	4	10		E
40	5	11	A	
40	6	12	A	
50	3	-		F
50	4	-		G
50	5	-	A	
50	6	-	A	

Figure 14. Column Diameter D vs p's for $b_v = 0.75\ b = 0.75\ mD$



H_M Wave Height (FT)	m	Curve Labels		
			p (all)	
		p_{AC}	p_{HT}	p_{TR}
20	3	1		B
20	4	2	A	
20	5	3	A	
20	6	4	A	
30	3	5		C
30	4	6	A	
30	5	7	A	
30	6	8	A	
40	3	-		D
40	4	-		E
40	5	-	A	
40	6	-	A	
50	3	-		F
50	4	-		G
50	5	-	A	
50	6	-	A	

Figure 15. Column Diameter vs p's for b_v = b = mD

3 - 73. Static Stability. Static stability is important to any floating body. If static instability exists, the body will not remain upright but will rotate on the water surface to a point where stability does exist. It is important to this floating island concept that a large island be stable after it is completed and that smaller islands should also be stable to facilitate handling during erection and assembly as well as to accomplish certain missions for small islands.

3 - 74. Static stability is critical about the least dimension of the island module. Accordingly a single row of inflatable columns representing the width was selected and a parametric approach to column diameter, spacing, unit weight of the above-water portion, height of center of gravity of this weight above water, and number of columns of a module was made for nautical static stability as a limiting condition.

3 - 75. Righting moment is a function of the metacentric height. The metacentric height is the distance computed from the center of buoyancy to the metacenter and is given by the equation.

$$\overline{BM} = I/V$$

If the center of gravity is below the metacenter, the body will float stably with center of gravity directly above the center of buoyancy.

3 - 76. For a series of equal circular waterline intersections such as in an array of floats, the moment of inertia, I, is the sum of the circle inertias and the inertia transfer function of each float to the center line of the array. Each float contributes the inertia

$$I = \frac{\pi r^4}{4} + \pi r^2 a^2$$

3 - 77. If the support columns are ballasted with water having a free surface, the effect is to eliminate the $\pi r^4/4$ term from the expression for I. If the air-water interface comes at the attenuator hinge, the term may be retained; however, since for practical designs, $a^2 >> r^2/4$, it is negligible in any case. The attenuators are assumed to weigh the same as the water they displace and so do not affect the location of the center of buoyancy.

3 - 78. If all the floats are of equal diameter and equidistant apart

$$\overline{BM} = \frac{b^2 (n-1) (n+1)}{12\ell}$$

The center of gravity may be determined from Figure 16, which shows a unit column supporting a unit uniform surface in a uniform array. Then by symmetry the height of the center of gravity of a unit will be the same as that of the whole module.

3 - 79. The curves generated from this equation can be used to verify the stability of specific proposed designs. Typical plots have been shown in Reference 2.

3 - 80. These results show the point of neutral stability. As the center of gravity rises, it passes from stable to unstable. The center of gravity must always be below the metacenter when the module is floating free. The exact distance is not critical. Large ocean liners often are designed to have about a two foot distance for comfort. U.S. Maritime rules require at least two inches under the worst condition of flooded compartments.

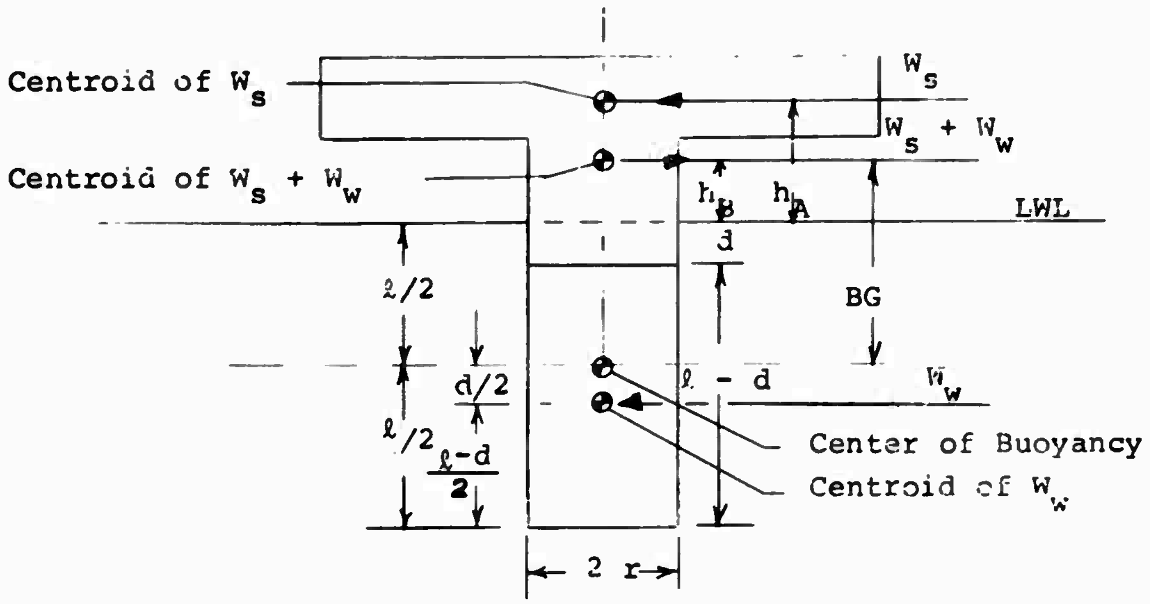


FIGURE 16 - UNIT MODULE SCHEMATIC

3 - 81. From moments about center of buoyancy,

$$\overline{BG} = \frac{2\ dh_A + d^2}{2\ \ell}$$

or converting draft "d" into unit structure weight plus load,

$$d = \frac{w\ ab}{64\ \pi\ r^2}$$

where $w = W_s/ab$ and $b = .866a$ for staggered columns.

$$\overline{BG} = \frac{w \left(\frac{b}{r}\right)^2 \left[128\ \pi h_A + \left(\frac{S}{r}\right)^2 w\right]}{2(64\ \pi)^2\ \ell}$$

Equating $\overline{BM} = \overline{BG}$, which is the point of neutral stability:

$$h_A = \frac{64\ \pi r^2 a^2\ (n-1)\ (n+1)}{12\ w\ ab} - \frac{w\ ab}{128\ \pi r^2}$$

Where h_A is the minimum height of the metacenter M above the still water line for static stability. The same result can be obtained by disregarding the water-filled portion entirely so that $\overline{BG} = h_A + \frac{d}{2}$.

3 - 82. From inspection of the equation and the shape of the curves, it may be seen that increasing the number of columns increases the width and likewise the stability. Increasing the diameter of the columns have a stabilizing effect by reducing the draft required to support the load.

3 - 83. Increasing the spacing with the same unit weight increases the load required of each column and is destabilizing. Increasing the unit weight is the strongest destabilizing input into the equation.

3 - 84. Consider as an example a deck designed for 40,000 lb aircraft and weighing 30 psf exclusive of attenuators. Also let r = 3 ft and a = 18 ft with staggered rows of columns and a half-bay overhang at the edges. If a 40,000 lb aircraft lands, w is increased by a factor of $\frac{40,000}{.866\ (18n)^2}$. Table 3-7 shows the effect on the metacentric height h_A for this specific case. If h_A is appreciably greater than the freeboard, say h_A > 30 to 40 ft., static stability exists; otherwise a check of the c.g. location is necessary.

TABLE 3-7 - METACENTRIC HEIGHTS OF BASES WITH n^2 FLOATS CARRYING m AIRCRAFT

		h_A, Ft.				
n	(n-1) (n+1)	m=0	m=1	m=2	m=3	m=4
3	8	44.1	26.7	17.7	11.8	7.6
4	15	84.6	62.9	49.4	40.0	33.1
5	24	136.6	114.0	97.6	97.9	77.2

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3 - 85. Eccentric Loading. A floating body may be stable when loaded symmetrically, yet capsize when an eccentric load of sufficient magnitude is applied. The floating base is unlikely to capsize in a 7x7 column array, but an undesirable amount of tilting might be encountered. Assuming the maximum permissible angle of tilt to be that which starts to bring the attenuators above the still water line:

$$\tan \theta = \frac{2d}{(n-1)b} \quad (= \theta \text{ for small angles})$$

3 - 86. If W is the total weight of platform and deck loading, the overturning moment is

$$M_W = W\,(\overline{GB} \sin \;\; + e \cos \theta\;)$$

For small angles θ, and assuming that the centroid of W is at the deck floor level, h_d,

$$\overline{GB} = h_d + \frac{d}{2}$$

so,

$$M_W = W\,(h_d\,\theta + \frac{d\theta}{2} + e)$$

Also for small angles, the righting moment is

$$M_B = \rho\,\theta\,I$$

Equating $M_B = M_W$ to obtain the equilibrium attitude yields

$$W_e = (\,\rho\,I - W\,h_d - W\,\frac{d}{2}\,)\,\theta$$

The equation above has been evaluated in Figure 17 for various values of k and n=6, 7, and 8, with θ as previously defined.

3 - 87. Ordinates have been divided by b to make the graph applicable to scale models. Since the c.g. of the platform is below the deck level, the curves are conservative for low aircraft loadings and probably for all practical loadings although the aircraft centers of gravity are above the deck level.

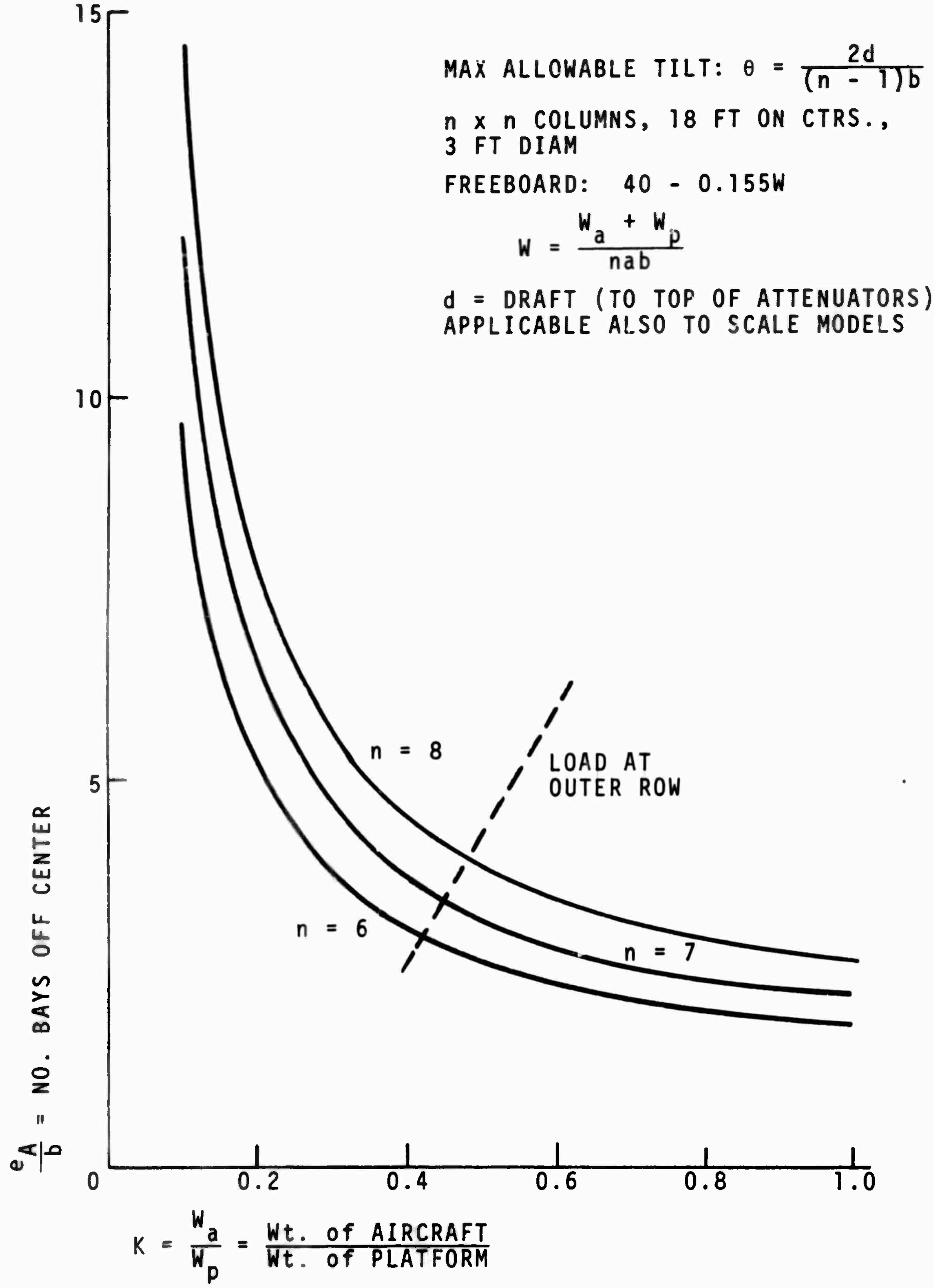

Figure 17. Permissible Eccentricity of Superimposed Load Floating Base

3 - 88. Four design concepts were presented in the Phase I design studies. While each concept had its own distinct virtues, each had its minor variations in packaging. All configurations, however, had a similar basic approach in discussing erecting, packaging and transporting.

3 - 89. Assembly of the island is conducted on a slotted work platform which is constructed above the erection ship's main deck with a portion extending beyond the ship's side (See Figure 18). The slots in the platform provide room for the floats and attenuators while the panels are connected on the work platform surface. As the hexagonal panel units are assembled together on the work platform, the assembled island portion is pushed outward. When the floats are free of the ship's side but still supported by the work platform, they are inflated and the trusses are connected. Then the assembled portion can support itself and maintain a horizontal attitude as that portion is pushed off the work platform. When a sufficient portion of the island is extended to provide stability, mobile pump units and supplies can be transferred to the island to begin attenuator water filling, erection of hangars, living quarters, etc.

3 - 90. For a test base with an array of floats 7 x 7, there would be 49 floats, attenuators and service panels and 392 standard panels. Assuming that the truss system would be attached and that the attenuators would be water filled while other assembly procedures were being accomplished, it is estimated that the total erection time would be approximately 57 hours.

3 - 91. The floating island components must be capable of being packaged within reasonable sizes and weights to facilitate transportation. Smaller packages generally adapt more readily to various handling equipment and methods. Package density for a complete island varies from about 10 to 25 pounds per cubic foot which indicates that volume may be a greater problem than weight with regard to transportation.

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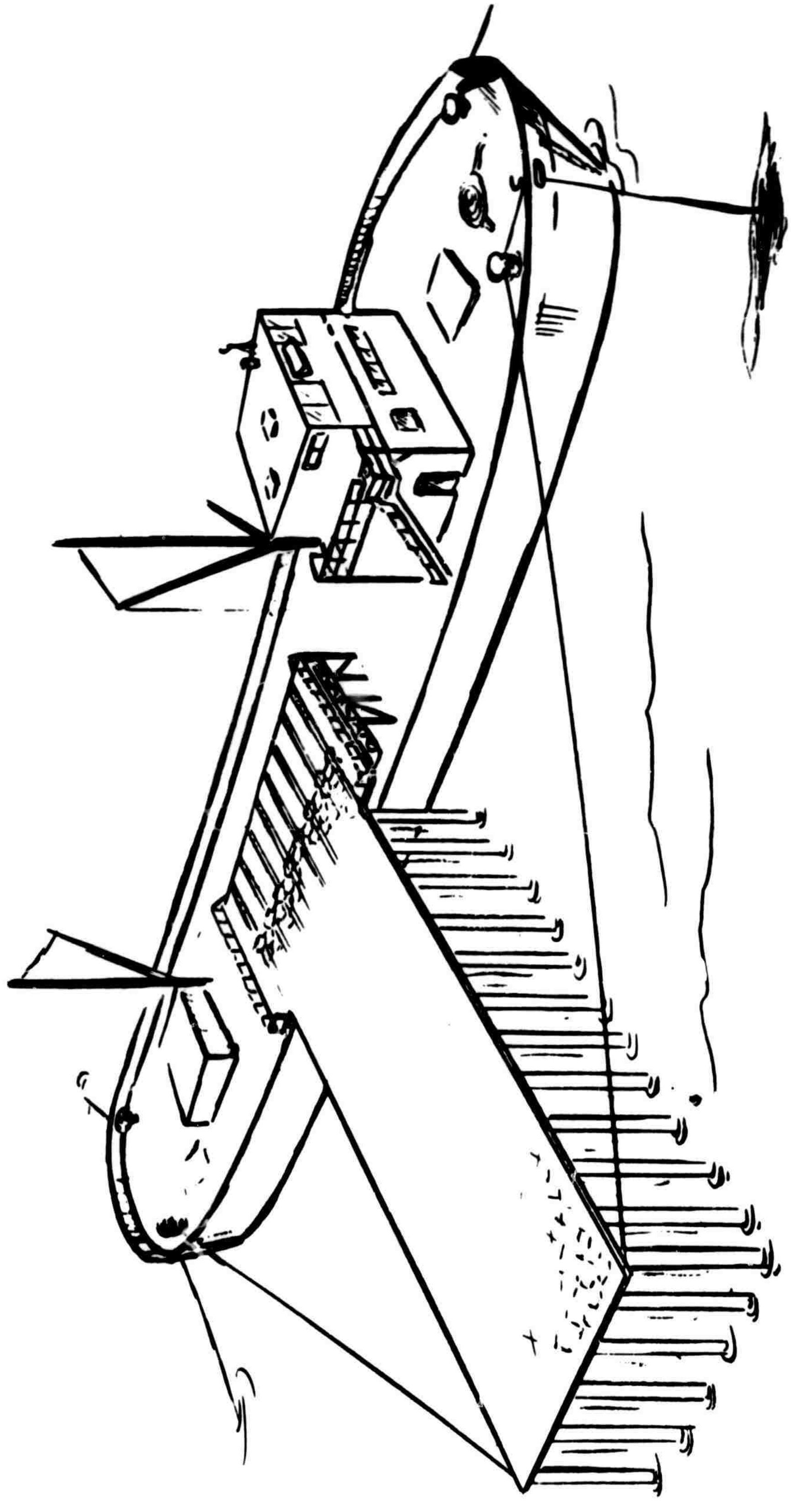

Figure 18. Island Erection Utilizing Special Work Platform

3 - 92. The following table shows estimated package sizes, weights, and quantities for a representative sandwich panel deck configuration of a 100 x 100 ft size designed to be operational in sea state 5 with a landing deck 30 ft above the still water level and capable of supporting a 100,000 lb aircraft at 1.5 g's.

TABLE 3-8 - PACKAGE SIZE AND WEIGHTS

Item	No. of Packages	Package Dimension, Ft.	Package Weight, Lb.	Total Wt., Lb.
Floats	42	7 x 4.5 x 9	3880	162,960
Attenuators	42	11.5 x 9.5 x 9	5020	218,400
Panels	14	20 x 7 x 6	19,000	266,000
Cables	2	24 x 2 x 2	11,000	22,000
Total Volume		65,142 Cu.Ft.	Total Weight	669,360 Lb.

3 - 93. To transport a representative island base by C5A cargo aircraft, which have a payload capacity of 265,000 lbs., would require at least 3 craft, based on weight. However, volume being more critical than weight for some of the packages, four of the C5A's cargo compartments (121 x 19 x 13.5 ft) would be needed to hold the packages if their dimensions were as given in Table 3-8.

3 - 94. A similar analysis has been conducted for transportation by Lighters (bafges that are floating cargo holds). Using the example previously used, the island structure could be contained in the capacity of 3 1/3 Lighters, each with a capacity of 19,600 cu.ft.

3 - 95. The flexible fabric materials from which an expandable structure is composed combine an elastomer and reinforcement material to obtain the required strength. One of the advantages of this type construction is that each ply of material can be positioned so that it will match the existing stress levels, thus providing a minimum thickness and a maximum load resistance.

3 - 96. The flexible fabric materials have two major components; the fiber from which the cloth is woven and the elastomer used to seal and protect the fiber.

3 - 97. The most desirable characteristics of fibers for expandable structures are:

1. High strength-to-weight ratio
2. Compatibility with the projected coating
3. Ease of construction
4. Good energy absorption

3 - 98. Experience has shown that both nylon and Dacron fibers are very acceptable materials to use for expandable structures. The preference for these materials is perhaps due to lower cost, greater experience in handling, and ease of manufacturing.

3 - 99. The choice of coating and bonding material is related to the environmental conditions and must be compatible with the base-fabric material. Requirements such as mechanical working (folding and packaging), creep characteristics, temperature, ease of manufacture, and resistance to fuels, ozone, and fungus must be considered before all elastomeric material can be finally accepted.

3 - 100. Since the environment is one of the primary considerations in the design of an expandable structure, numerous test programs have been conducted to obtain design information.

3 - 101. These environmental test programs have accumulated considerable data pertaining to the life characteristics, marine fouling, and structural integrity of elastomeric materials in an ocean environment.

3 - 102. Figure 19 shows the results of creep-rupture tests conducted on specimens immersed in sea water both with and without seams. Figure 20 shows the results of tests conducted on various materials soaked in sea water under a no-load condition. Samples of each material were removed at given intervals and tensile tested to failure. The results shown are average values of this sampling.

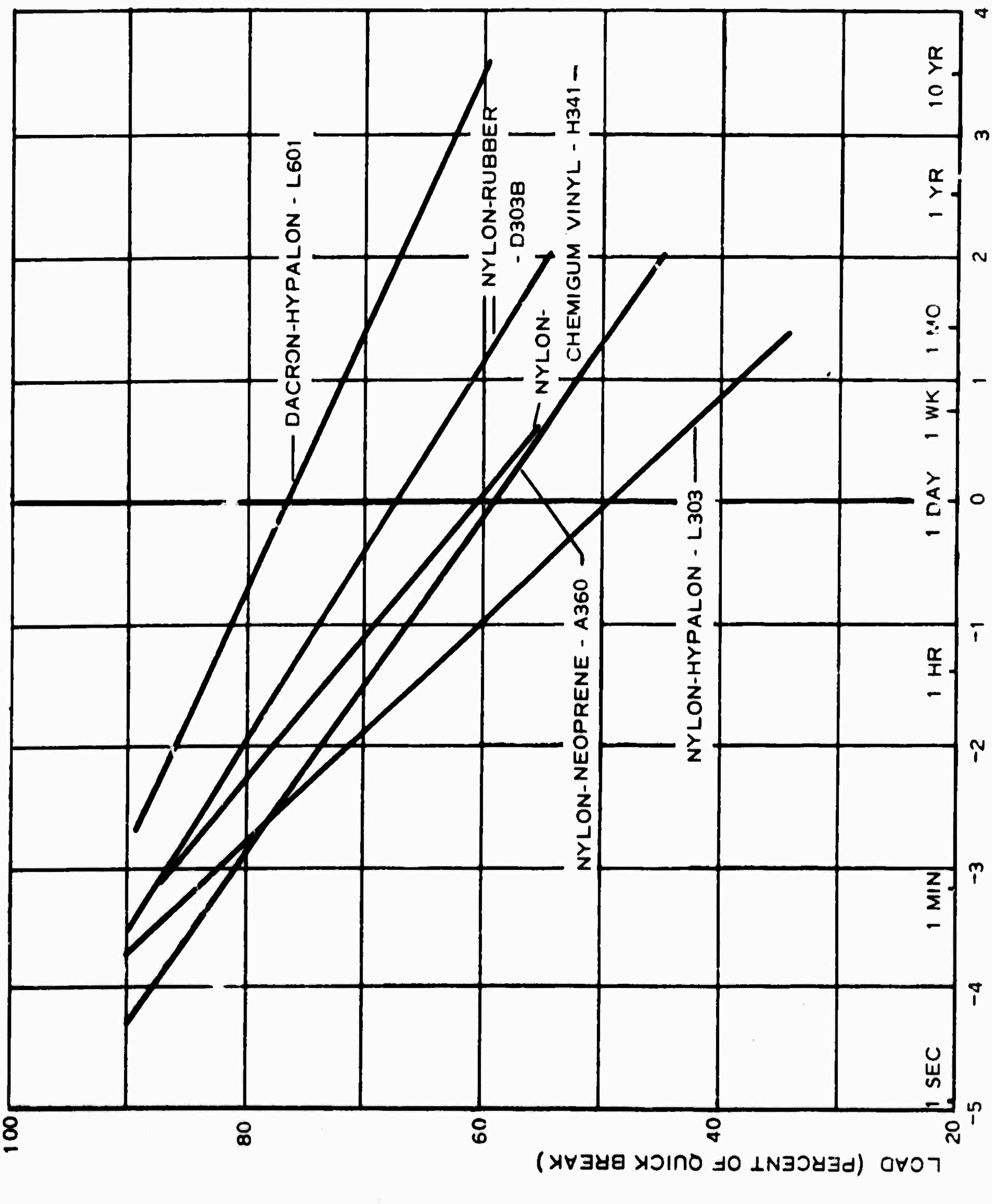

Figure 19. Load VS Time in Salt Water - No Seams

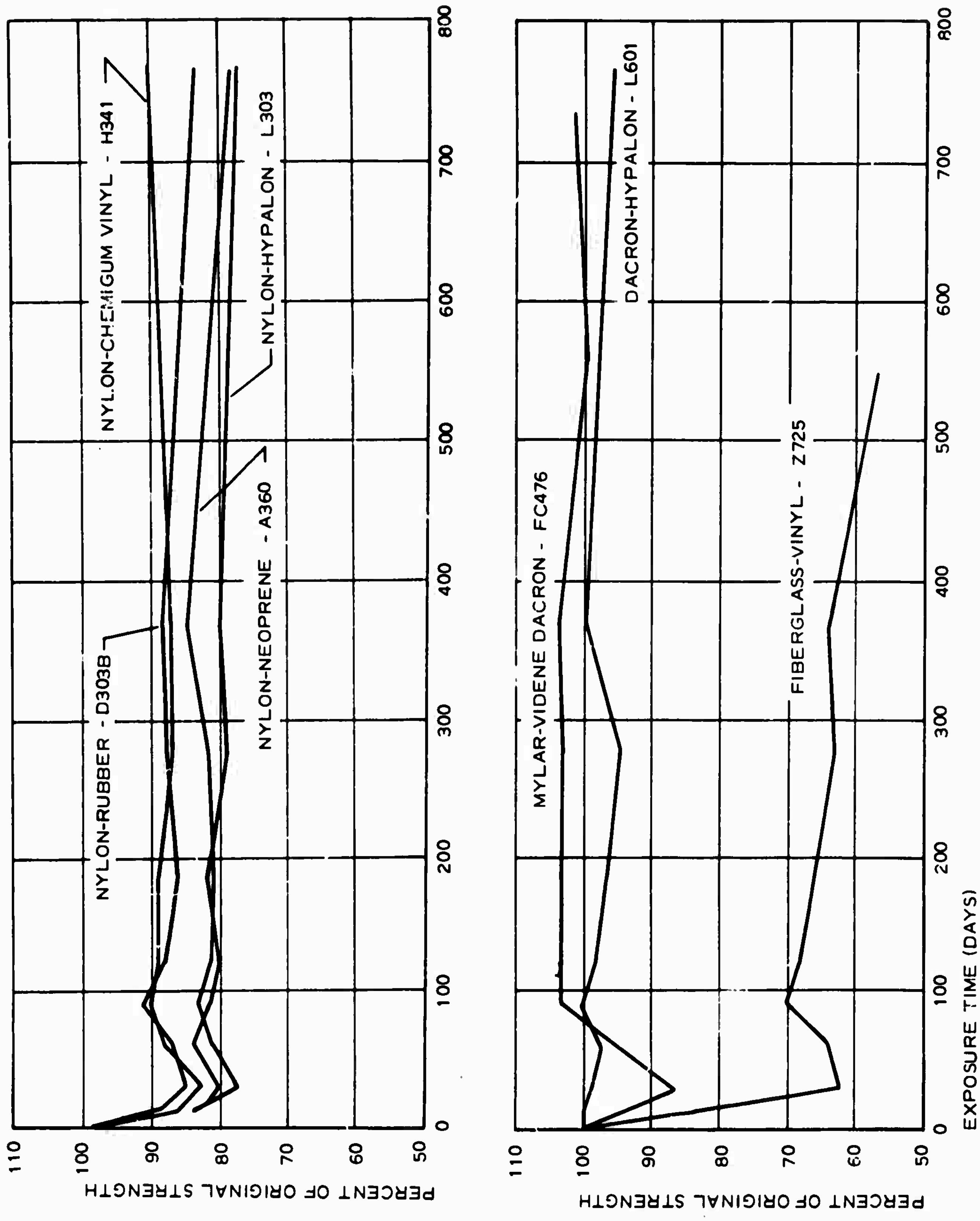

Figure 20. Sea Water Soak Tests - No Load

3 - 103. As a result of informal discussions with personnel from both Goodyear Research and E.I. DuPont de Nemours, it was recommended that the most acceptable fabric reinforced elastomeric material for long term service in sea water would be a composition of Dacron fabric impregnated with Goodyear Tire and Rubber Company's anti-foulant neoprene compound MA-852 with 4.5 percent bis- (tri-W-butyl tin) dioxide (TBTO) or its equivalent added as the antifoulant. Tests indicate that these materials are the most economically acceptable and that their performance would be equivalent to or better than any other materials which might be selected.

3 - 104. An investigation of the potential service life of cable materials in a sea water environment was conducted, resulting in the conclusion that cable service life may be shorter than for any other component in an Expandable Floating Base. The best cable recommendation would be a high strength, high carbon steel, either aluminized or galvanized coated, encased in a polypropylene or polyethylene jacket.

3 - 105. Perhaps a better material from the standpoint of strength and resistance to sea water environment would be one of the titanium alloys, such as 6Al 4V. Since this material is not fabricated into cable, its use in this application would require a design using segmented bars or rods in place of the cable where possible. In addition to an assumed lower initial cost, the rods made from a steel currently in use by the shipbuilding industry would offer superior corrosion resistance to that of the cables.

3 - 106. PHASE II - Design Testing and Analysis.

3 - 107. The design testing plan was reviewed with respect to the results and recommendations reached at the conclusion of Phase I. It was recommended that the configuration as shown in Figure 3 should be pursued at the present time since the deck surface of that configuration is within current state-of-the-art fabrication. This approach would permit the evaluation of one unknown, the

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vertical floats, and would make possible the earlier availability of a Floating Base at a more economical cost. One impact this approach made was to permit the fabric test program to be completed in an abbreviated form.

3 - 108. The objective of the fabric materials test program was to obtain the strength characteristics of available high strength fabric and to attempt to develop a simple, low cost seam which, at 75°F, would have at least the same strength as the basic fabric in which the seams were made. A second objective was to use a minimum adhesive build-up system to prevent stiff joints from occurring which would limit packageability or foldability. A third objective was to obtain a cement system which would minimize the seam strength degradation when exposed to 140°F temperature condition. Time-load seam strength or creep rupture data on these seams was also obtained. These data have been reported in Reference 13.

3 - 109. In the landing deck analysis, the deck was considered as a continuous plate supported on rows of equidistant columns. Solutions exist for some problems of this type, such as for a uniformly distributed load, and others can be derived by superposition. However, a general solution for a single load distributed over a small area at any point on such a plate did not appear to exist in the literature, and a solution using a digital computer was developed.

3 - 110. Because the deck was not a uniform continuous plate, consisting as it does of hexagonal panels assembled with joints that (with small deflections) can transfer only shear normal to their lengths, a continuous plate solution was not entirely adequate. This was in part accounted for in Reference 2 by considering the deck to be only 2/3 effective in resisting bending. It was believed important, however, to examine the problem in more detail, considering the actual load paths by which a load on a given hexagonal panel was transferred to the columns.

3 - 111. The details and results of this additional analysis of the landing deck are contained in Reference 14.

3 - 112. A comprehensive exploratory program of analysis and model testing by the Davidson Laboratories of Stevens Institute of Technology (under subcontract to GAC) was undertaken to provide hydrodynamic information necessary for design and evaluation of the closely-packed vertical floats and attenuators envisioned for the expandable floating base. The results of this program are reported in Reference 15.

3 - 113. The model tests included two series of investigations of the influency of proximity on the wave-induced forces on two alternate float shapes. Complimentary tests with isolated versions of these floats were also carried out. In addition, a number of other tests, such as forced heave and surge oscillations, studies of the action of hinged motion attenuators in waves and when undergoing forced oscillations, were conducted with these floats and with several other floats including a flexible, hydroelastically-scaled model. The effectiveness of a variety of sizes and locations of damping plates was investigated.

3 - 114. An analytical program was initiated to correlate with the experimental work in order to permit generalization of results for performance evaluation of alternate designs. A rather elementary combination of slender body theory with linear wave theory was adopted. Since the ocean's wavy surface is irregular and random, the motion and force responses of the floats must be treated statistically, combining ocean wave spectra with response transfer functions to obtain response spectra, from which the statistical quantities of the response can be derived.

3 - 115. Considerations of weight, space, arrangements and cost dictate the need for the shortest possible float which must consequently be somewhat enlarged below the waterline for two reasons:

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to increase the inertia and thereby reduce the heave natural frequency, and to diminish the vertical wave-induced force by adapting the float shape to the wave pressure gradient. As the design philosophy calls for the smallest reasonable motion in a realistic random sea, described by an energy spectrum, it is not surprising that the heave natural frequencies of acceptable float shapes are slightly lower than the low frequency (long wave length) cut-off of the design sea spectra. Thus, the float shape is selected so that it acts as a vibration isolator. If the float shape is excessively full below the waterline, the wave-induced forces due to pressure gradient will be large in the downward direction in way of the wave crest and, in spite of relatively low natural frequency, effective vibration isolation may not be achieved. Since it is impractical to design floats for an Expandable Floating Base whose natural frequency is so low that no ocean waves exist which could excite it (and, indeed, the natural frequency must be fairly high for practical reasons), it is considered that energy-dissipating damping plates must be fitted to the floats to control resonant motions.

3 - 116. Interaction and Isolated Float Tests. In previous experience with floating platforms such as for drill rigs, hydrodynamic interaction between adjacent floats was found to be negligible. The large numbers of floats planned for the Floating Expandable Base are so closely packed in relation to their size that it was considered vital to investigate the interaction between floats at an early stage of this program. If the interaction is either sufficiently small or amenable to rational approximation, then the hydrodynamic analysis of the influence of variations in float size and proportions on performance can be based on the results of theoretical analysis and model tests of isolated floats.

3 - 117. Wave-induced forces were measured on individual floats in an array consisting of five rows of five floats each. The force-measuring balance could be moved so that forces on any one of the floats could be measured, as desired. The spacing of the floats was either three times the waterplane diameter or five times. Two sets of floats having different proportions and drafts were tested with and without damping plates.

3 - 118. Certain general findings of the tests can be given: the side forces and pitching moments acting on the floats due to waves are practically uninfluenced by proximity; the vertical wave-induced force is modified by an apparent increase in an added-mass type force component which is significant for higher frequencies and accounts for about a 30% increase above the isolated float results for the fatter of the two floats studied, and; damp-plates attached in way of the fat lower parts of the floats may result in severe interaction influence on the drag-type force component but plates may be attached to the slender upper part of the float without important interaction.

3 - 119. Some results for vertical (lift) force on a rather short, full float, both isolated and in the middle of the 25 float array are exhibited in Figure 21, which shows the increase in force at high frequency. The dimensions of the float are illustrated in this figure as well. The introduction of a ten-foot diameter damping plate at the junction of the conical transition piece and the upper float produced only a minor increase in lift force at high frequency. Rather similar results were obtained with a deeper, more slender float, but damping plates having 13.5-ft diameter were fitted to the lower end of the floats, the wave forces were dramatically increased evidently because of a drag-type component in phse with the vertical wave velocity. The forces on the interior float elements of the array were found to be virtually the same as one another while the floats in the forward row (near the wave generator) and in the aft row were close to the results for isolated floats.

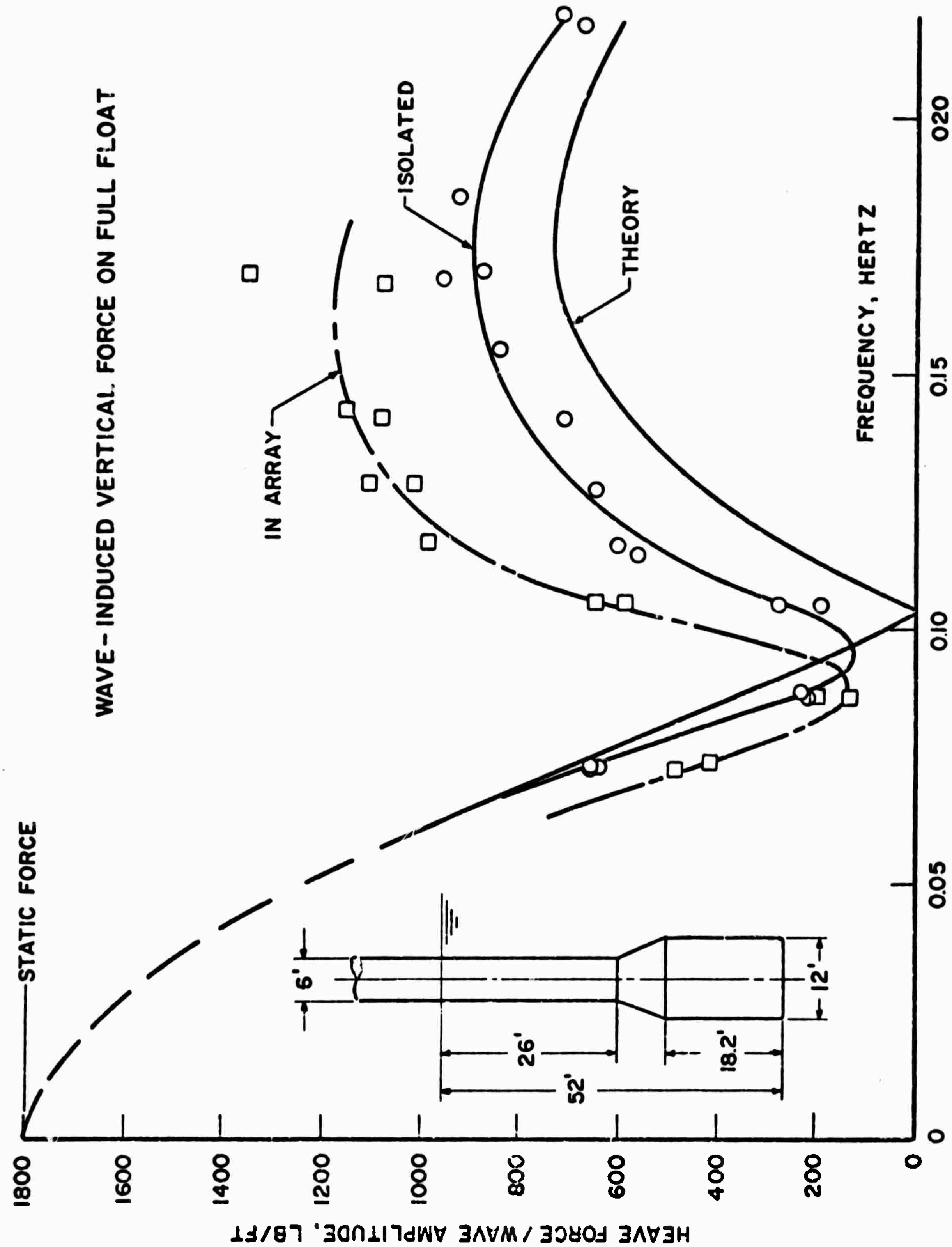

Figure 21. Wave-Induced Vertical Force on Full Float

3 - 120. Horizontal forces measured on the float of Figure 21, isolated and in array, are shown in Figure 22. It was found (somewhat surprisingly) that little or no interaction occurs for this component of force and the floats in array experience essentially the same side force as the isolated floats.

3 - 121. Also shown in Figure 22 are some results of another kind of investigation. A hinge was used to permit the lower end of the attenuator to oscillate like a pendulum under the action of the waves. In this way the periodic side loads due to the waves are not completely transmitted to the Floating Base connecting structure by way of bending moments in the float but are rather absorbed by the pendulum-like motion of the attenuator. This reduces the strength requirements of the inflated float and, consequently, weight and cost. The side forces measured on the float of Figure 22 when a hinge was introduced at a location 23-ft below the waterline, are seen to be remarkably lower than without the hinge. The amount of angular motion, which is greatest for low frequencies of course, is about 3-deg per foot of wave elevation for a frequency of 0.07 hertz. Only isolated float tests have been conducted with a hinge thus far. It is anticipated, in view of the absence of interaction influence on the side force for rigid floats, that there will be little or no influence for hinged floats. It is important to note that the hinge had virtually no effect on the vertical float force due to waves.

3 - 122. A variety of other tests were also carried out, using several float models and with various damping plates fitted. Besides wave tests, forced heave and surge oscillation tests were carried out, and a few tests with freedom to heave (but not surge or pitch) were performed in waves. Results of these tests are to be presented in Reference 15 for this phase of the hydrodynamic investigation.

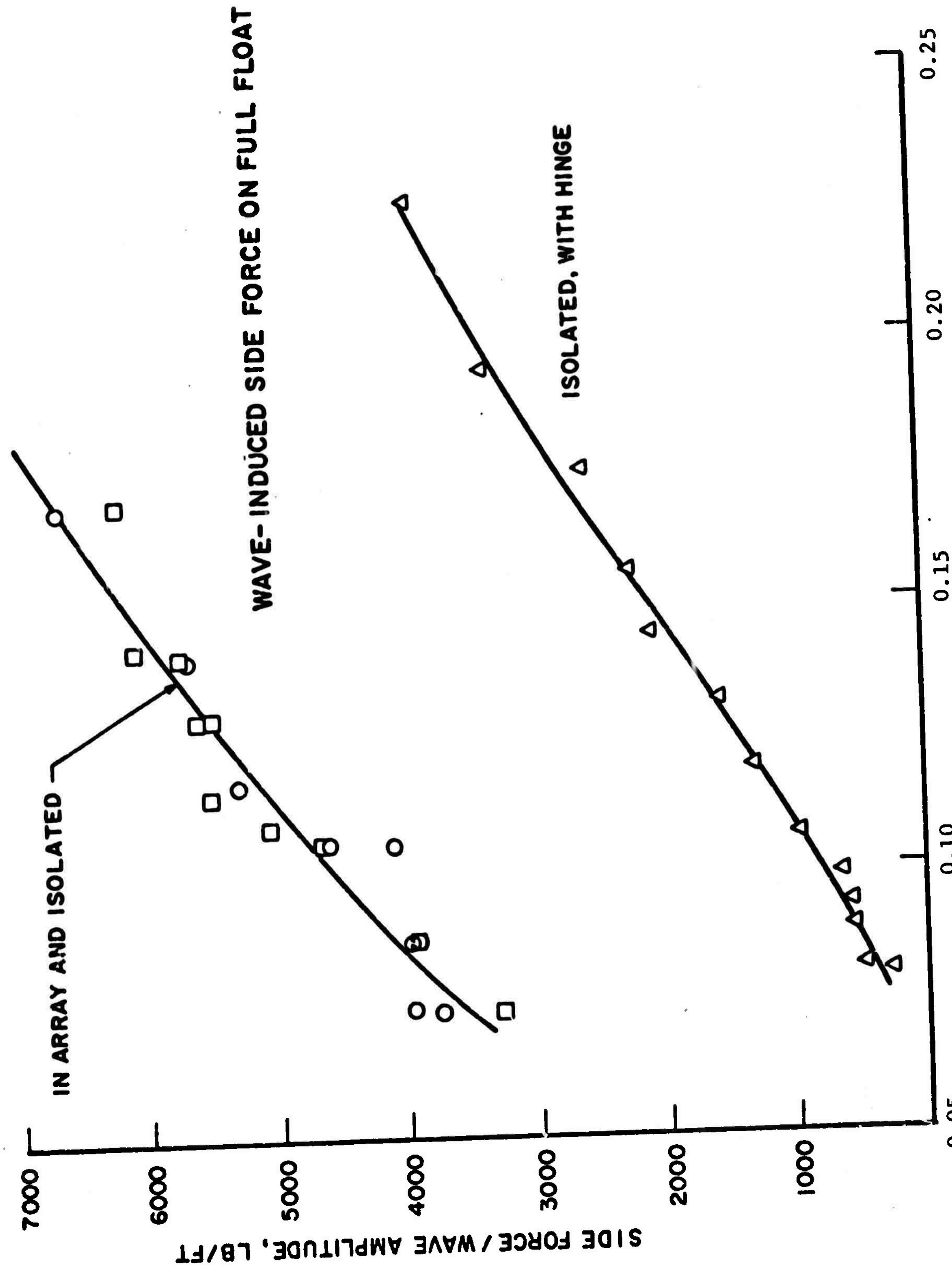

Figure 22. Wave-Induced Side Force on Full Float

3 - 123. Model Dynamic Island Tests. A freely-floating model of a substantial segment of a Floating Expandable Base was tested in regular and irregular waves. The 1/57.6-scale model had thirty-five rows each with six floats like those shown in Figure 21. The rows of floats were rigidly connected to a cross-brace above water. Rows of floats were connected to each other by parallel motion linkages which permit freedom to heave while restraining against pitch motions. Because of these linkages, the model was not stable in pitch so a free-to-heave mast was rigidly connected to the center row of floats to artifically restrain pitch. In fact, great care and effort had to be exercised to obtain roll stability and zero neutral roll angle with this model. In addition, the parallel linkage mechanism afforded virtually no restraint against racking (twisting) of the rows of floats or against a longitudinal accordion-type (buckling) behavior, so a pair of light-weight plastic strips were fitted at the "gunwales" of the model. The model had a thin sheet of polyethylene plastic as a deck, part of which was marked to appear similar to a non-precision instrument airfield runway. It should be pointed out that the problems mentioned above were symptoms of model structural difficulties which are greatly different from full-scale characteristics.

3 - 124. The model was moored, or restrained, against drift and yaw by bow and stern spring lines. These may have a small influence on surge oscillations as well.

3 - 125. Vertical deck motions were measured at five locations along the centerline of the base segment, at rows 1 (forward), 9, 18 (middle), 27 and 35 (aft end). Results of regular wave tests of various frequencies are shown in Figure 23 for rows 1, 18 and 35, together with a theoretically calculated transfer function. It is seen that the motions are generally higher than the theory for higher frequencies and that the frequency for null (small) motions, and the natural frequency are both lower than theoretical. These findings are in accord with the vertical force data measured

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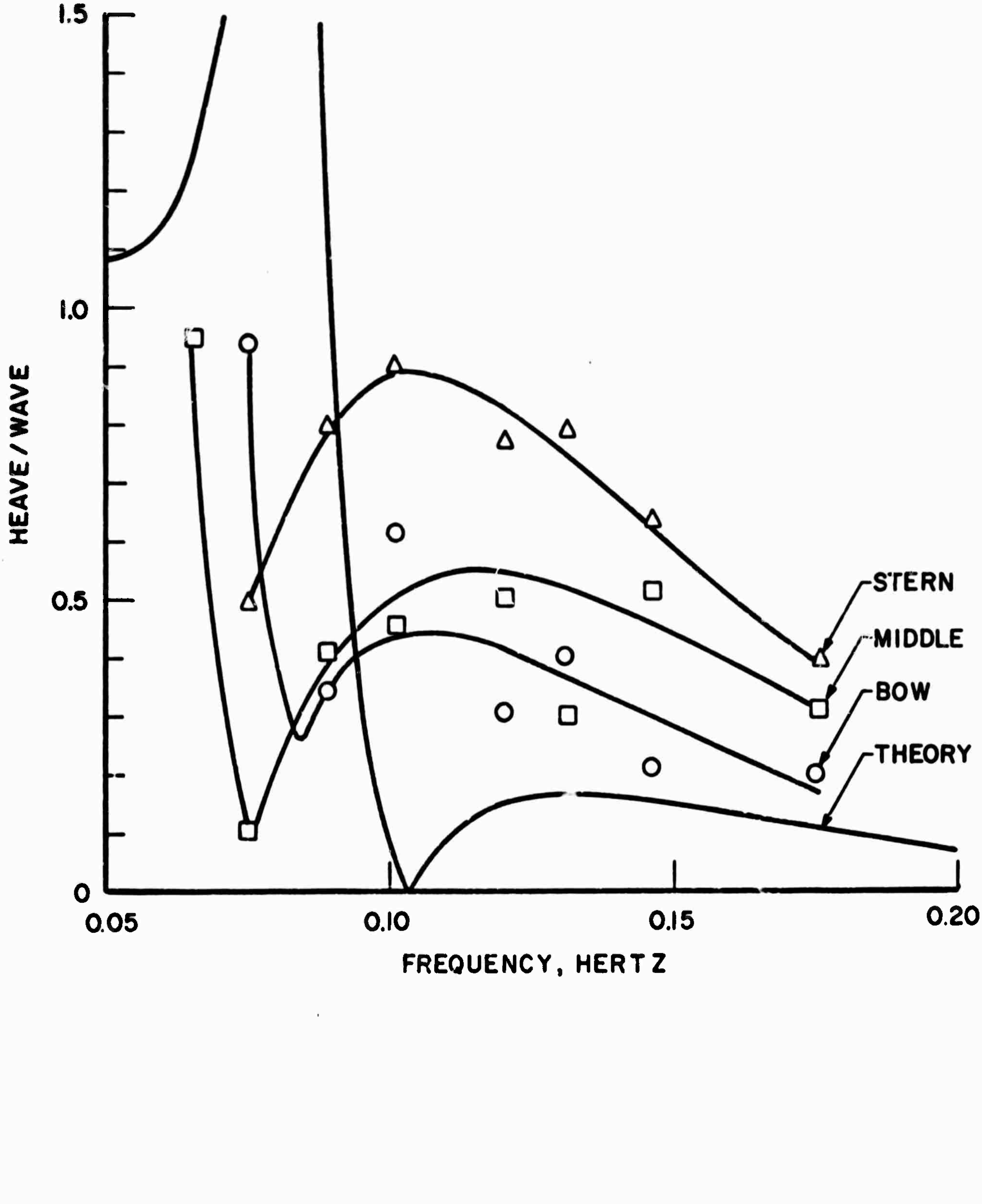

Figure 23. Model Island Heave Motion

in the array of 25 floats and are presented in Figure 21. The deck motion appears to have greater amplitudes as the aft end of the model (away from the wave generator) is approached. There is as yet no explanation for this behavior but it may be associated with the model's mooring and surge restraint arrangement.

3 - 126. Irregular wave tests were also carried out with this model in waves having significant heights of 6.9, 10, 15 and 30 feet and spectral distributions like the Pierson-Moskowitz formulation. These significant heights correspond to the less precise seafarer's designation of Sea States 4, 5, 6 and 7, respectively. Heaving oscillations at row 18 (middle of the expandable base segment) have been analyzed to determine the significant heave motion (average of the one-third highest), the average of the one-tenth highest, and the greatest motion measured. Results are given in Table 3-9.

TABLE 3-9 - HEAVE MOTION IN IRREGULAR WAVES

Significant Wave Height, $H_{1/3}$	Significant Heave Motion, $z_{1/3}$	Average 1/10 Highest Heave	Greatest Measured Heave
6.9	1.95	2.76	3.16
10.0	3.66	5.48	7.59
15.0	5.25	7.04	8.40

Model tests in 30-ft significant height waves were aborted before collecting sufficient data for analysis. Structural damage to the model was feared.

3 - 127. The particular float geometry used for these floats is not suitable for the Floating Expandable Base. Although according to the unmodified theory it satisfies the heave motion criterion, the experiments demonstrate that it does not perform sufficiently like the theory. A somewhat deeper, more slender float design is expected to perform in conformance to the criteria.

3 - 128. PHASE IIa -- Systems Analysis.

3 - 129. General. In December 1970, GAC was requested to conduct a brief Systems Analysis on Expandable Floating Bases. This Systems Analysis Program had as its primary objective the determination of typical Expandable Floating Base component sizes, weights and cost per square foot of deck area based on sea states and mission loadings.

3 - 130. Other objectives included:

a) An investigation of methods of island erection.
b) An investigation of packageability and portability.
c) An investigation of ancillary equipment necessary for erection and maintenance on station.

3 - 131. The results of these latter three items have been incorporated into the results of the overall program and will not be discussed in this section separately.

3 - 132. The design approach selected for this System Analysis was based on the recommendation made at the conclusion of the Phase I - Study. That approach was designated as Configuration III.

3 - 133. The Configuration III Floating Base concept consists of a structural deck made from an adhesive-bonded sandwich panel with integral extruded edge members. The deck transfers the mission load [airfirld, radar installation, or others] to the floats.

3 - 134. The floats, which support the deck off the water surface, are made of expandable structures. These air inflated floats or columns serve three functions: they transmit the loads from the deck into the truss of which they form a part; they act as compression members in the truss webbing; and they transfer the static and dynamic forces to and from the water and to the vertical motion attenuators located below the floats.

3 - 135. The attenuators, which reduce the deck oscillations, are attached to the bottom of the floats or columns and are filled with water. They effect their purpose by virtue of both their shape and their mass. The attenuators are sized to have a heaving natural frequency lower than the lowest wave frequency in the maximum energy band of the design sea state.

3 - 136. A truss system of cables or tie rods join the columns together. A bottom chord was assumed effective for concave upward bending. The diagonal members together with the columns carry shear.

3 - 137. Since there were no specific missions, loads, or sea states stated for this System Analysis, it was conducted somewhat parametrically. However, to hold the magnitude of this analysis to an acceptable level of effort, a certain number of parameters in this study were held constant. The following loads and conditions were considered:

Assumed Loads - The floating base was studied for aircraft having the following take-off weights:

A - 155,000 Lbs
B - 100,000 Lbs
C - 40,000 Lbs

Critical Loading - The critical deck loading of 1.5 g's [limit] occurs during taxiing the airplane.

Operational Sea States - Three different designs were considered structurally with respect to sea state: one for a sea state of 7, another for a sea state of 5 and the third for a sea state 0.

Survival Condition - An operational design can survive approximately twice the operational wave height. A survival wave of 60 feet [double amplitude] has also been considered in the structural analysis.

Factors of Safety - The following factors of safety were applied to the limit loads:

Type of Structure	Operational Yield	Operational Ult.	Survival Yield	Survival Ult.
Fabric				
Buckling or Collapse		2.0		1.0
Tension		*		*
Cables	1.33	2.0		1.25
Sandwich Panels	1.33	2.0		1.0
Other Metal Components	1.33	2.0		1.0

*In accordance with Reference 2 [Page 36] a strength reduction factor of 5.0 for loads of long duration and of 4.0 for loads of short duration was used. This factor is intended to account for the reduction in strength of the material in service as compared to the "quick-break" strength obtained in laboratory tests. Some of the factors causing this reduction in strength are weathering, fatigue and creep. The strength reduction factor in addition includes an adequate margin of safety.

3 - 138. As this systems analysis progressed it became apparent that the cost was not within the cost region of $30 to $50 per square foot of area as suggested by ARPA in the 14 December meeting. Therefore, GAC initiated a Value Analysis Program to investigate other means of achieving the same objective but at a lower cost. The Value Analysis Program was funded entirely by GAC in support of this Expandable Floating Base program.

3 - 139. Systems Analysis Program. The following design criteria were used to configure the components of Expandable Floating Base in order to obtain a cost relative to sea conditions and aircraft load.

3 - 140. Floats or Columns - The columns were spaced 18 feet apart in a pattern of equilateral triangles. They were designed using fabric having a "quick-break" strength of not more than 3000 lbs/inch. Two configurations of floats were considered: a 6 ft diameter fabric cylindrical tube and a cluster of seven 2 ft diameter tubes. The latter configuration was able to carry more load using the same fabric because it can be inflated to a higher pressure. The bottom of the deck supported by the floats would be at least 30 feet above the surface of the water in calm water - sufficient to clear a 60 ft wave. For estimating this, the structure was assumed to weigh 35 lb/ft^2, which for the 6 ft diameter tubes, gives a draft of 5.4 ft.

3 - 141. Deck Panels - The deck panels were sandwich construction using an aluminum alloy or other metal which would be highly resistant to sea water corrosion for the face sheets and for the edge extrusions. The core of the sandwich was considered to be made from either cored redwood or balsa wood. The panels would be sealed to prevent water permeation of the core material. The deck was made up of hexagonal panels having a dimension across the flat sides of the hexagon of six (6) feet. One surface of the deck panels would have a non-skid surface treatment.

3 - 142. Trusses - The diagonals consist of steel cables or tie rods having slopes approximately equal to 45°. Since the column spacing was 18 ft., two bays of bracing form, with a lower chord and the columns, a truss 36 ft deep. A third bay of bracing was also considered for some cases. The floats were made 40 ft long for the two-bay design, which allows for a superimposed deck load of almost 30 psf. The three-bay design requires a 58 ft float ballasted with 18 ft of water. [The third bay of bracing serves to reduce the strength requirements of the attenuators to resist side loads.]

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3 - 143. Attenuators - The attenuators were designed to be made of fabric and filled with water. They were sized to limit the double amplitude displacement of the deck to 2 feet. The criteria used to determine the size of the attenuators has been cited earlier in this report.

3 - 144. Using the previously stated assumed requirements and design criteria, an analysis was conducted to determine the size of the various components in Expandable Floating Bases. This study included both a structural analysis and a hydrodynamic analysis. Table 3-10 summarizes the sizes of the components as calculated from the criteria assumed. Estimated wieghts are shown in Table 3-11. Hydrodynamic testing to refine the size and shape of the attenuator was conducted after this analysis was completed.

3 - 145. The load capacity of a Floating Base is limited by a variety of considerations some of which are shown in Figure 24. The figure reflects a base designed to land a 40,000 lb airplane, and also shows survival limits in high seas without aircraft on deck.

3 - 146. As weight on the deck increases, the base sinks deeper into the water and the reduction in freeboard lowers the height of waves before they break over the deck. If the load continues to increase, eventually, the base will sink to a point corresponding to zero wave height. The "Total Weight" curve in Figure 24 shows this variation. Six-foot diameter floats 18 feet apart in staggered rows are assumed. The parallel dashed line in the figure is derived from the "Total Weight" curve by subtracting a structure weight of 30 psf to get the superimposed deck load.

3 - 147. The deck limitation of 500 psi is in calm water with a factor of safety of 2.0. This would indicate a much larger load than the 40,000 lb airplane for which the deck was designed. This is because the load is assumed uniformly distributed while the

Table 3-10. Summary of Island Component Sizes

	Sea State	Wave Height (Ft.) Operational	Wave Height (Ft.) Survival	Airplane Weight (LBS) Operational	Airplane Weight (LBS) Survival	Sandwich Deck Hex. Panels Total Thickness (In.)	Sandwich Deck Hex. Panels Al. Skin Face Thickness (In)	Columns No. of Tubes	Columns Tube Dia. (Ft)	Lower Chords Cables No.	Lower Chords Cables Diameter (In)	Diagonals Cables No.	Diagonals Cables Diameter (In)	Attenuators Maximum Dia. (Ft.)	Attenuators Length Ft.
OPERATIONAL CONDITION ONLY	0	0	-	40,000	0	6.0	.156	1	6	2	5/16	2	1/4	NONE	
				100,000	0	9.5	.247	1	6	2	5/16	2	1/4	NONE	
				155,000	0	11.0	.286	7	2	2	5/16	2	3/8	NONE	
	5	13	-	40,000	0	6.5	.169	1	6	2	7/8	2	3/8	6	66
				100,000	0	10.0	.260	1	6	2	7/8	2	7/16	6	66
				155,000	0	11.5	.299	7	2	2	7/8	2	1/2	6	66
	7	38	-	40,000	0	7.5	.195	7	2	4	1-1/8	2	1/2	15	67.5
				100,000	0	11.0	.286	7	2	4	1-1/8	2	1/2	15	67.5
				155,000	0	12.5	.325	7	2	4	1-1/8	2	9/16	15	67.5
OPERATIONAL AND SURVIVAL	0	-	60	40,000	0	6.0	.156	7	2	4	1-1/4	2	1/2	15	67.5
				100,000	0	9.5	.247	7	2	4	1-1/4	2	1/2	15	67.5
				155,000	0	11.0	.286	7	2	4	1-1/4	2	1/2	15	67.5
	5	13	60	40,000	0	6.5	.169	7	2	4	1-1/4	2	1/2	16	67.5
				100,000	0	10.0	.260	7	2	4	1-1/4	2	1/2	15	67.5
				155,000	0	11.5	.299	7	2	4	1-1/4	2	1/2	15	67.5
	7	38	60	40,000	0	7.5	.195	7	2	4	1-1/4	2	1/2	15	67.5
				100,000	0	11.0	.286	7	2	4	1-1/4	2	1/2	15	67.5
				155,000	0	12.5	.325	7	2	4	1-1/4	2	9/16	15	67.5

Table 3-11. Estimated Component and Total Weights of Floating Base

	Sea State	Wave Height Oper	Wave Height Survival	Airplane Weight Pounds	UNIT WEIGHT - POUNDS/FT² OF DECK								
					DECK					TRUSS			
					Core	Face Sheet	Extrusion	Total	Column	Column to Deck Attach.	Cables Diag-onal	Cables Chord	Cable Attach.
OPERATIONAL CONDITION ONLY		0		40,000	3.560	4.009	9.622	17.191	2.961	2.078	.240	.067	.061
	0		-	100,000	5.645	6.350	12.123	24.118	2.961		.240	.067	.061
				155,000	6.511	7.344	13.085	26.940	6.917		.530	.067	.119
		13		40,000	3.849	4.362	10.006	18.217	2.961		.530	.552	.216
	5		-	100,000	5.933	6.671	12.508	25.112	2.961		.776	.552	.266
				155,000	6.831	7.697	13.470	27.998	6.917		.999	.552	.310
		38		40,000	4.458	5.003	10.776	20.737	10.026		1.498	1.849	.669
	7		-	100,000	6.511	7.344	13.085	26.940	10.026		1.498	1.849	.669
				155,000	8.371	7.409	14.240	30.020	10.026		1.930	1.849	.756
OPERATIONAL AND SURVIVAL		-		40,000	3.560	4.009	9.622	17.191	10.026		1.498	2.231	.746
	0		60	100,000	5.645	6.350	12.123	24.118	10.026		1.498	2.231	.746
				155,000	6.511	7.344	13.085	26.940	10.026		1.498	2.231	.746
		13		40,000	3.849	4.362	10.006	18.217	10.026		1.498	2.231	.746
	5		60	100,000	5.933	6.671	12.508	25.112	10.026		1.498	2 231	.746
				155,000	6.831	7.697	13.470	27.998	10.026		1.498	2.231	.747
		38		40,000	4.458	5.003	10.776	20.237	10.026		1.498	2.231	.746
	7		60	100,000	6.511	7.344	13.085	26.940	10.026		1.498	2.231	.746
				155,000	8.371	7.409	14.240	30.020	10.026	2.078	1.930	2.231	.832

Table 3-11. Estimated Component and Total Weights of Floating Base (Continued)

	Sea State	Wave Height Operational	Wave Height Survival	Airplane Weight Pounds	Unit Weight - Pounds/Ft² of Deck: Attenuator Column	Attenuator Attach	Total	Total Wt/Panel 31.18 Ft²	Total Weight/Repeating Section 9 Panels
OPERATIONAL CONDITION ONLY	0	0	-	40,000	-	-	22.598	704.6	6,341
				100,000	-	-	29,525	920.6	8.285
				155,000	-	-	36,651	1142.8	10.285
	5	13	-	40,000	3.271	.556	28.381	884.9	7,964
				100,000	3.271	.556	32.611	1016.8	9,151
				155,000	3.271	.556	42,681	1330.8	11,977
	7	38	-	40,000	10.983	.556	47.896	1493.4	13,441
				100,000	10.983	.556	54.599	1702.4	15,322
				155,000	10.983	.556	58.198	1814.6	16,331
OPERATIONAL AND SURVIVAL	0	-	60	40,000	10.983	.556	45.309	1412.7	12,714
				100,000	10.983	.556	52.236	1628.7	14,658
				155,000	10.983	.556	55.052	1716.7	15,450
	5	13	60	40,000	10.983	.556	46.335	1444.7	13,002
				100,000	10.983	.556	53.230	1659.7	14,937
				155,000	10.983	.556	56.116	1749.7	15,748
	7	38	60	40,000	10.983	.556	48.355	1507.7	13,569
				100,000	10.983	.556	55.058	1716.7	15,450
				155,000	10.983	.556	58.656	1828.9	16,460

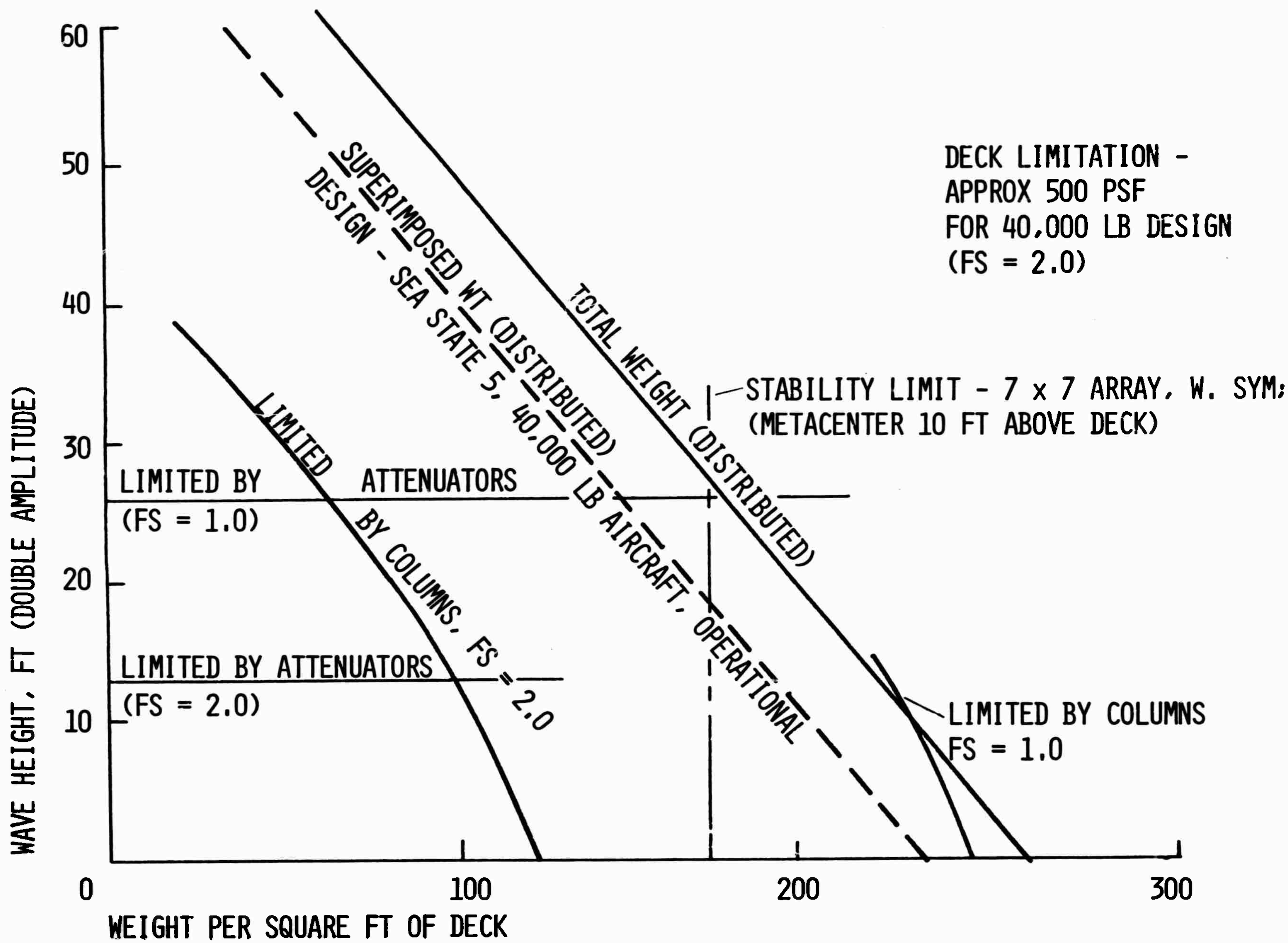

Figure 24. Limiting Wave Heights and Distributed Loads

airplane load is concentrated at the landing gear. Interaction of wave loadings with deck loading is probably linear, but is not shown. Column loads depend on deck loading and wave forces. The curve marked F.S. = 2.0 is an operational limit. The curve marked F.S. = 1.0 indicates a collapsing limit.

3 - 148. The attenuators are designed for a 13-ft wave height, operational (F.S. = 2.0). The lower of the two curves labeled "attenuators" shows this limit. The upper curve, marked F.S. "1.0, gives a collapsible load limit. It is possible that buckling of the attenuators would not be a catastrophe; however, the deck and lower chord cables can resist only a little more load. The attenuator forces do not depend on the deck loading, assuming the changes in freeboard are minor; hence, the lines are horizontal.

3 - 149. The stability of a small base is a function of loading and of the float size and arrangement. An array of 49 floats 18 feet apart in 7 staggered rows is assumed, which leaves the minimum row spacing at 15.6 feet. The metacenter is kept 10 feet above the deck floor to allow for aircraft c.g.'s and asymmetrical loading. The mass of the attenuators is disregarded since they are hinged and are assumed neutrally buoyant.

3 - 150. Wave forces, in general, have been assumed to be proportional to wave height. This is probably conservative.

3 - 151. Cost Comparison. One of the objectives of the Systems Analysis Program was to provide a budgetary estimate for the costs os an Expandable Floating Base per square foot of deck surface area. The costs shown herein are for the configurations [Operational] studied during this part of the program. The configurations represent variations in load carrying capabilities, sea states in which the base would be operational and quantities of manufacture. A summary of these conditions, including the number of components required and their sizes has been shown in Table 3-9. The cost data generated which is shown in Figure 25, are based upon preliminary design information generated during this phase of the

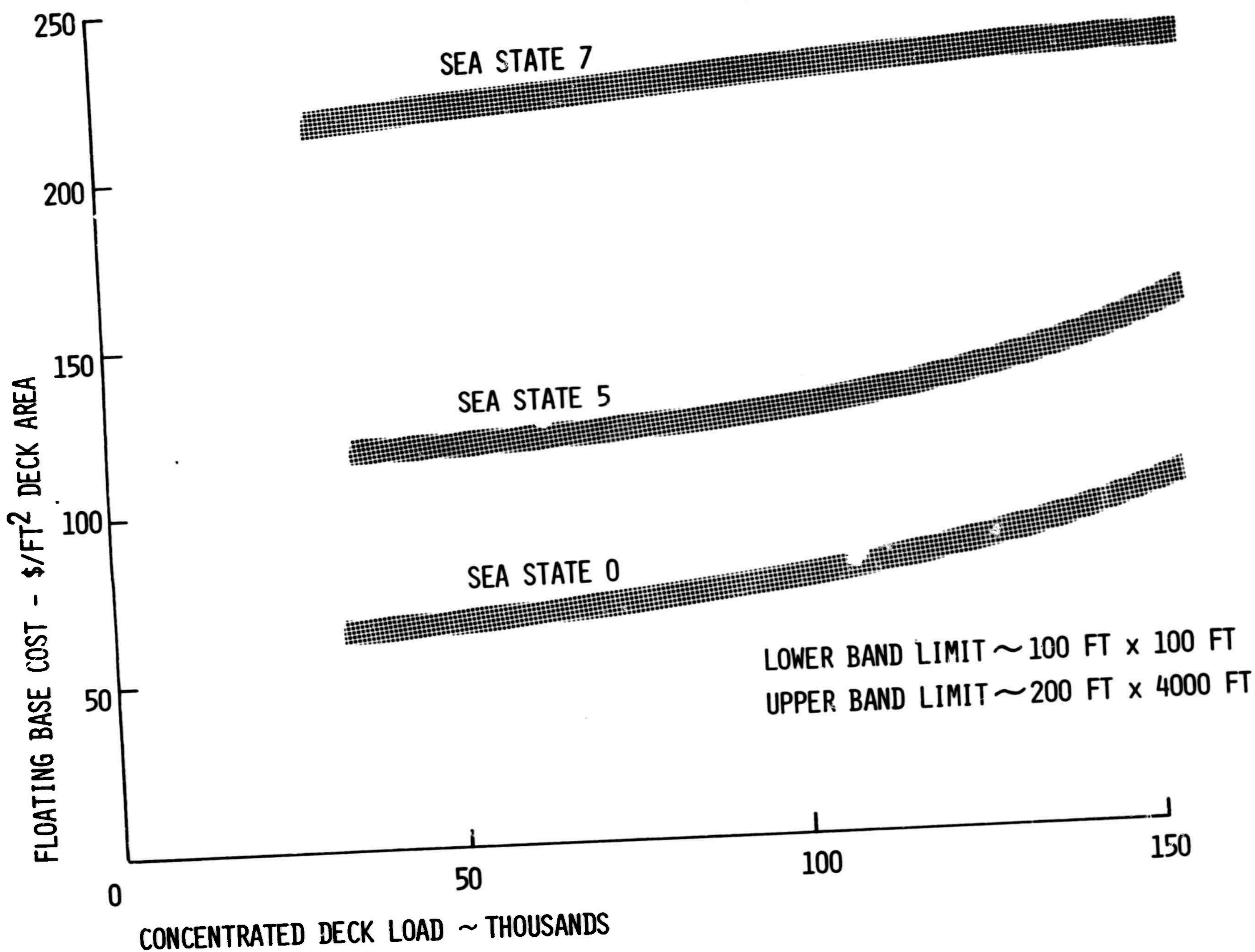

Figure 25. Concentrated Deck Load vs Floating Base Cost

program for this purpose and utilize current manufacturing processes.

3 - 152. Two sizes of base were considered; i.e., a 100 x 100 feet nominal size base and the other, a 200 x 4000 feet nominal size base. Longer production runs for the manufacture of more than one base of either size could reduce the cost of manufacture as shown,but could require additional capital equipment. Improved manufacturing techniques are also anticipated with larger production requirements and this could extend the state-of-the-art manufacturing practices to permit a further reduction in cost.

3 - 153. The costs which are shown provide the recurring costs for the fabrication of the Floating Base components. Improved or new manufacturing facilities would be required if a large number of components were required in a short period of time. These costs are not included.

3 - 154. The items estimated included costs after appropriate facilities are established of -

(1) Standard Deck Panels
(2) Service Panels
(3) Floats
(4) Tie Rod Bonds
(5) Tie Rods
(6) Hinge
(7) Attenuators
(8) Damping Plates
(9) Miscellaneous Hardware
(10) Associated Cost and
(11) Material Burden, General and Administrative Expenses and Profit.

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3 - 155. Miscellaneous hardware includes valves, fittings, and manifolds for the air and water inflation while Associated Cost are the engineering, liaison during manufacture, inspection, manufacturing planning and quality assurance.

3 - 156. As anticipated, the cost of manufacture increases with both load carrying capability of the base and sea state. The method used in making the estimate did not show that a significant cost advantage would occur as the volume of manufacture increases. Costs varied from a value of approximately $65 per square foot for an island capable of handling a 40,000 pound load, operational in calm water to a high value of $237 per square foot for a 155,000 pound load operational in a sea state of 7.

3 - 157. These costs assume that a design commensurate with the production facilities has been established, that appropriate scale model fabrication and tests have proven this design and that the production learning period has been completed.

SECTION IV

RECOMMENDATIONS

4 - 1. General.

4 - 2. Within the capability of this program, the data obtained indicates that an Expandable Floating Base is feasible. However, with the introduction of specific missions, which could change the loading conditions, and by adding other restraints such as cost, packaging ratio, erection capability, etc., the degree of feasibility which was obtained may be more definitely confirmed.

4 - 3. Most of the effort in this program has been confined to a theoretical investigation supported by limited testing, in accordance with the original program plan. However, these plans were changed in order to provide funding for the hydrodynamic testing portion of the program.

4 - 4. Although the present program has shown technical feasibility from a theoretical viewpoint, it is recommended that a program now be initiated to demonstrate this technical feasibility in the areas of fabrication, erection, and testing. An approach to this type of program will prove the technology involved in an Expandable Floating Base. The primary recommendation is, therefore, the continuation of its development through the completion of prototype fabrication and test.

4 - 5. The complete Expandable Floating Base development program time schedule, as envisioned by Goodyear Aerospace Corporation, is shown in Figure 26. Some changes to this program may result as additional data becomes available, and some areas of investigation may precede others due to available funding or priorities. However, it is believed that this schedule represents a realistic program for the successful development of a full scale

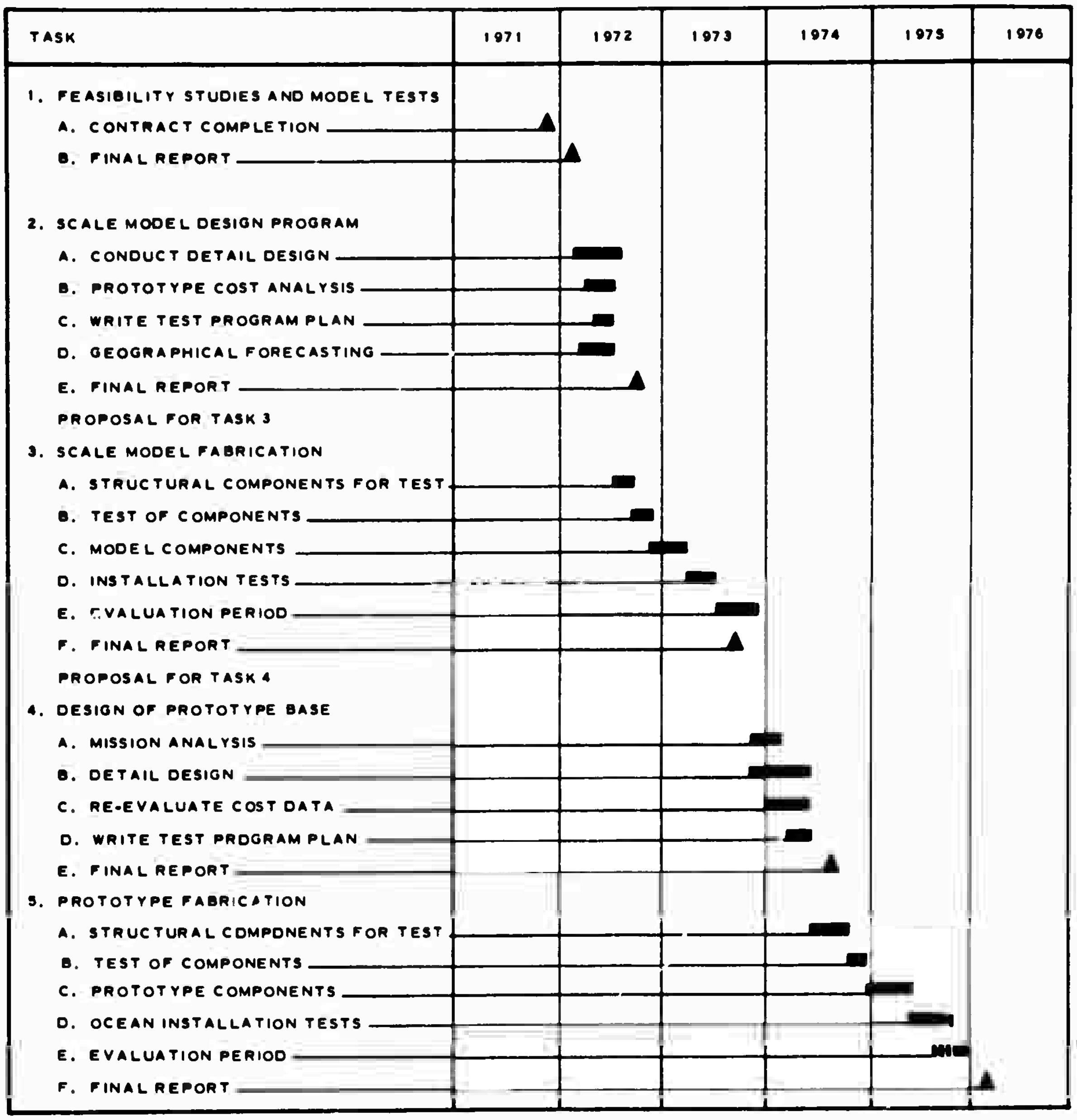

Figure 26. Total Program Schedule

prototype Expandable Floating Base. In the time schedule, that point in the program which has now been reached is shown, as are the tasks which remain for the successful development of this concept.

4 - 6. A "Task" numbering system has been employed to help in this discussion. The recommended tasks are those which demonstrate the feasibility of the program by showing that a full-scale Expandable Floating Base is within current state-of-the-art technology. The technology can be demonstrated best by a program which would begin now to accomplish the design, fabrication and testing of a base approximately 1/3 full size. The tests on a scale model of this size would be conducted on an inland lake. After an evaluation of these tests, the full scale prototype base would be designed, fabricated and tested.

4 - 7. For purpose of discussion, all effort on this contract has been assumed to be part of Task 1. The recommended program to establish the overall objectives is described as Tasks 2 through 5 in the following paragraphs. The next task in this development program is the effort which is now recommended under Task 2 and is detailed in paragraphs 4-12 through 4-27 of this report. This effort, which is the detailed design of a 1/3 scale Expandable Floating Base, would be completed in approximately 6 months.

4 - 8. Task 3 encompasses the fabrication of the 1/3 scale components, structural testing and incorporation of required modifications, installation for testing on a lake, and performance evaluation of the scale model base over a period of time.

4 - 9. During the performance evaluations, the design of a prototype base, Task 4, would be started. The design would be based on the results obtained during Task 3 and would consider requirements based on a mission analysis conducted concurrently.

4 - 10. Task 5 would accomplish the fabrication of the prototype base. Limited testing of the components would be necessary to assure that the test results of the model components remain applicable in full scale. Following the assembly of the prototype base, the installation testing would be conducted.

4 - 11. This program was separated into Tasks to permit the accomplishment of major milestones placed throughout the program schedule prior to full commitment to the next task. The milestones represent critical points where evaluations may be made as to progress, anticipated success and need. It is also believed that this program time schedule will permit funding requests to coincide with budget allocations.

4 - 12. Discussion of the Recommended Task 2 Program.

4 - 13. The purpose of Task 2 in the development sequence of an Expandable Floating Base is to demonstrate that this concept is within current technology by the detail design of a one-third scale model base. The specific effort proposed herein is the design of the base and preparation of the "groundwork" as necessary to accomplish Task 3, which is fabricating and testing, and following Tasks.

4 - 14. The program schedule to achieve the design portion of this specific demonstration program is shown in Figure 27.

4 - 15. Detail Design Analysis.

4 - 16. The Expandable Floating Base concept selected during Task 1 has been shown in Figure 1. A preliminary design of the components believed critical to the determination of feasibility was also prepared during Task 1. As a result of that effort, lay-out drawings were completed for the major components including the deck, floats, support truss and attenuators and for the interfaces between deck panels, deck and floats, floats and truss, and floats and attenuators. The design was based on a sea state 5 operational

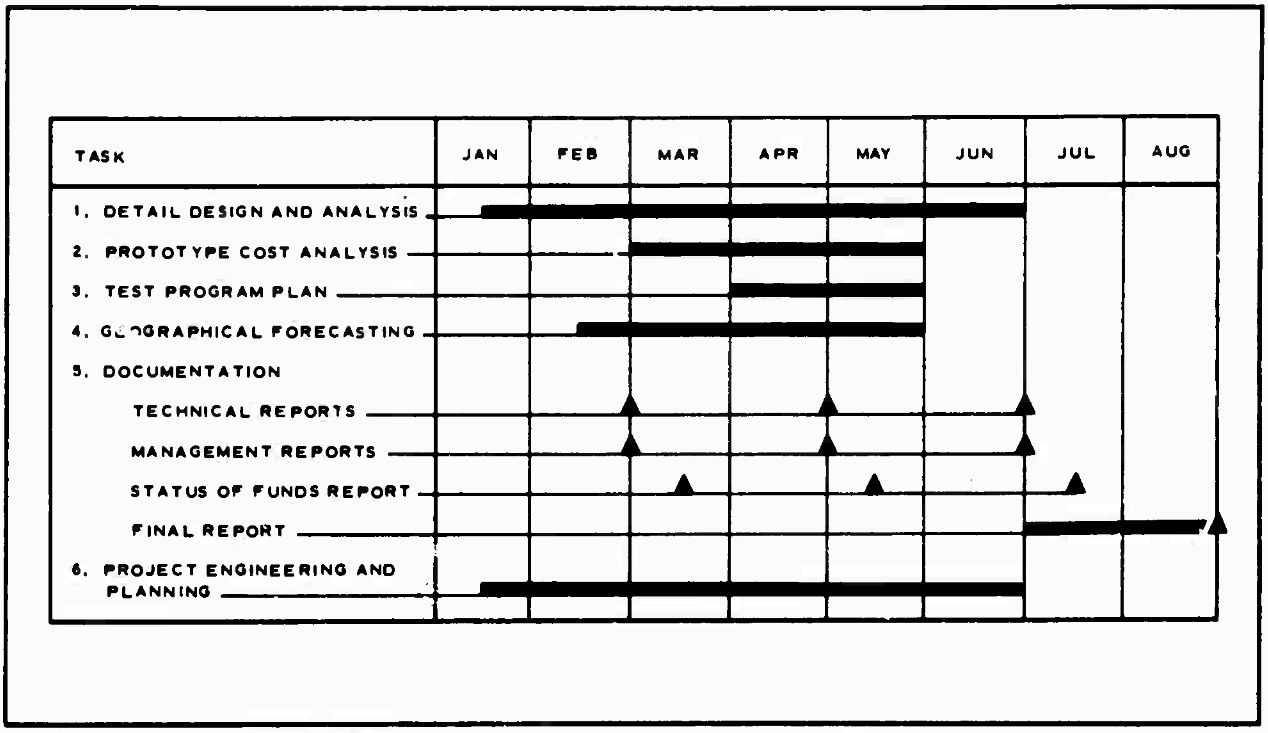

Figure 27. Proposed Program Schedule

condition and a 40,000 pound load. During Task 2, existing drawings will be detailed, with modifications introduced as necessary to tailor components to the scale selected. Other design modifications may be necessary to develop an erection sequence and assembly technique compatible with the lake implant operational testing. The design effort will also include the selection of support and erection equipment to support base operation after erection.

4 - 17. Davidson Laboratory of Stevens Institute of Technology will continue to provide consultative services on hydrodynamic loads and response behavior of the float elements and assembled scale model island.

4 - 18. Experimental data developed during the recent test program will be analyzed in greater detail to refine our hydrodynamic load analyses. These are theoretically-based, empirically adjusted calculation methods which permit the design-evaluation of the influence of float and attenuator shape and ridigity characteristics on the heaving motions, lateral restraint forces, attenuator hinge angular motions, and the deflections of the floats, all due to the action of waves. The initial analysis and exploratory test program has produced significant useful information, especially in regard to the hydrodynamic interaction influence of close proximity on the forces and motions of the floats, a characteristic feature of the island design. In particular, the vertical wave-forces on the attenuators have a substantially greater added-mass type component than is found in the corresponding isolated float, but the horizontal wave forces are not appreciably affected by proximity.

4 - 19. Although the exploratory test program indicated that from a hydrodynamic point of view, a successful design could be made to operate under the conditions of the tests, there remain several modes of operation which have not been investigated. These include towing, mooring in waves and in the presence of a current, and a more careful study of the effect of hinges on attenuator

behavior when in close array. Further model tests and analyses will be conducted to provide the additional guidance needed in these areas.

4 - 20. The small scale model tests will be carried out in the long wave tank where waves to sea state 7 and currents of virtually any magnitude can be simulated. The model will represent the scale model which it is planned to deploy at Seneca Lake, with a scale ratio of about 1/40 relative to the full-size (ocean-going) base. The structure and rigidity of this 7x7 array of floats and platform will be as similar as possible to the lake test version, including hinge connections of the wave attenuators. Various mooring and towing line arrangements will be studied, with and without waves, and measurements made of towline tensions (average and temperal variations). Motion picture records of above and below water behavior of the model will be made to observe heave, pitch and surge oscillations as well as hinged attenuator performance. The influence of wind loads will be briefly considered by using wind-generators during the model test program.

4 - 21. It is believed that motion damping plates will be required to control amplitude of heaving motion for relatively long waves corresponding to resonant periods which exist for sea states higher than the anticipated operational limit. Such damping plates have been found to be of great value, for instance, in controlling resonant motions of three and four float platforms designed for sea-based helicopters, aircraft or work platforms. A model test development effort will be undertaken to size and locate dampers suitable for the closely-packed float array.

4 - 22. The major components for design are listed and described below.

(a) Deck Structure

The deck panels will be designed using a bonded sandwich construction. The face sheets and interconnecting edge members of the individual panels will be designed to use an aluminum alloy or a steel which is highly resistant to sea water corrosion, while the core of the sandwich will be of balsa wood. Panels having a hexagonal shape will be used in the deck since the structure resulting from their interconnection appears to have the highest bending efficiency to carry the load. Based on a one-third scale of the 40,000 lb. load, the panels will be approximately 2-1/2 inches thick.

(b) Floats and Attenuators.

The floats will be cylindrical with their length and diameter approximately 1/3 of the size used in the preliminary design. They will be designed using an elastomer-coated cloth or a two-component construction employing an air-tight liner and a cloth load-carrying outer wall. Since all the parameters of a fabric structure such as strength, thickness, stiffness, etc. do not scale in the same proportions, design will be keyed to the factor believed to be most important in demonstrating the technical feasibility and packageability of these components.

The attenuators will be of a scale commensurate with the floats and deck, and will also be designed of elastomer coated cloth. The shape used will be based on that recommended by Stevens Institute of Technology as a result of their model test program during the initial contract on Expandable Floating Bases.

A flexible joint will be used between the float and attenuator to permit motion of the attenuator relative to the float and thus reduce the loads transmitted to the float.

(c) Trusses

In the existing concept, diagonals which form the truss needed to brace the floats will be steel tie rods having slopes approximately equal to 45°. During the design of the scale unit, attention will be given to developing a method of bracing which can be more readily installed at sea.

(d) Interconnecting Hardware.

Interconnecting hardware is specified as those components which attach the floats to the deck, the truss system to the floats, and the floats to the attenuators. In the current design, these components are a mixture of off-the-shelf hardware and parts which can be fabricated in Goodyear Aerospace shop facilities. The detail of how these components will be fabricated cannot be stated at this time, however, these designs must be compatible with the erection technique to be used.

(e) Erection System Components

The design will specify the equipment necessary to erect the Expandable Floating Base from the deck of the ship. This equipment is to include all compressors, pumps, hoses, fittings, etc., and will be delivered along with the island structure for the island assembly tests.

4 - 23. Prototype Cost Analysis

4 - 24. To insure that the overall objectives of the production Expandable Floating Bases are accomplished within a reasonable value per square foot of deck surface area, a cost analysis for the Prototype Base has been included as part of this statement of work. This cost analysis will be reviewed and "updated" in following tasks.

4 - 25. Test Program Plan

4 - 26. During the design, the plan for the test of the 1/3 scale components and the inland lake testing will be prepared. The tests to be planned are described below:

(a) Component Testing

(1) Fabric testing will be conducted to confirm that the proposed fabric materials will meet all structural and environmental requirements. Proof pressure buckling and packageability will be demonstrated during float and attenuator tests.

(2) Platform Deck Panel Testing. A test will be planned to investigate the load paths and stress distribution of the deck panels supported on a flexible foundation. This test is believed necessary since the design will present some new structural problems as a result of using a system of keys, connector rails or pins to provide ease of erection and individual panel replacement in the deck of the Base.

(3) Interconnection between Major Components. Proof loads will be planned for the test of connections between the floats and the deck, the floats and the attenuator, and the truss fittings to the floats.

(4) Support Equipment. Verification testing of the equipment selected for the erection and maintenance of the 1/2 scale model Base to be used at the inland test site will be planned.

(b) Inland Lake Testing.

The most important test to be planned in demonstrating the technical feasibility of the Expandable Floating Base concept will be that test which actually demonstrates the erection sequence in the inland lake environment. At the present time Seneca Lake in New York State is planned for this test site. It offers the necessary wave conditions, and test support may be obtained from the U.S. Navy Underwater Laboratory located there. In addition, the proximity of Lake Seneca to GAC, Stevens Institute and the Office of Naval Research will hold down transportation time and costs.

Davidson Laboratory of Stevens Institute of Technology will assist in the development of a detailed test plan for the large scale model Expandable Floating Base to be tested at Seneca Lake.

It is desired to measure quantities to verify or compare with design-analysis procedures. Davidson Laboratory will contribute primarily in the dynamic and hydrodynamic performance evaluations of these tests. Planning will be prepared covering measurements to be made, the instruments to be used, recording systems and data analysis, correlation procedures to be used, and the calibration and test procedures.

In particular, it will be necessary to correlate measured motions, accelerations, loads, strains, etc., with the waves. Davidson Laboratory has been active in developing field techniques for measuring sea waves, including directional wave spectra using various types of sensors.

Consideration will be given to testing for motion and structural response to vibration generator inputs and to selection of a suitable low frequency vibration generator apparatus.

Since ambient, wind generated waves may not occur at convenient data collecting opportunities during a relatively brief test span, a contingency plan for artificially generating waves in the vicinity of the (relatively small) scale model in the lake will be developed. For instance, regular waves of modest size could be generated by rolling oscillations of a large pontoon float produced by shifting of ballast; the pontoons' metacentric stability could be adjusted to permit various wave periods to be generated.

The test plan will probably call for prompt deployment of wind and wave sensing and some other apparatus so that environmental information could be logged during the scale model fabrication period prior to model erection and testing.

These tasks will be undertaken with the most careful attention given to field site facilities and capabilities. Several trips to the proposed test lake should be made during this test planning phase to ensure compatibility of sensors, signal conditioning apparatus, recording equipment, transmission cables, power supplies and storage and work spaces.

4 - 27. Geographical Forecasting. Deployment of an Expandable Floating Base in some part of the world's oceans entails possibility of exposure to winds, waves, currents, fog, rain, snow, etc., which may be more or less hazardous, depending on the particular site. As an exaggerated example, locating a large floating base in the vicinity of Cape Horn or the Cape of Good Hope would require extraordinarily rugged construction features which would not be justifiable in a majority of ocean base locations. Alternatively, there are sites with weather conditions so gentle that a base designed to be just sufficient for this locale would be in serious jeopardy in a more typical environment.

4 - 28. It is proposed that a brief survey be undertaken to map the frequency of occurrence of onerous weather conditions such as high winds, waves, snow, fog and so forth in various parts of the world's oceans. This is considered to be a key engineering investigation because of the influence of environmental conditions on the costs and technical problem areas of design for operability and survivability. Current information is also vital to the station-keeping performance of a floating base.

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LIST OF REFERENCES

1. Handler, E. H.: Tilt and Vertical Float Aircraft for Open Ocean Operations, Journal of Aircraft, Nov. Dec. 1966

2. GER 15048 Phase I Technical Report, Expandable Floating Bases - Goodyear Aerospace Corporation, November 15, 1970

3. Saunders, H.E.: Hydrodynamics in Ship Design, "Note for Volume Three on Maneuvering and Wavegoing", New York, The Society of Naval Architects and Marine Engineers, 1965

4. Brooks, R.L.; and Jasper, N.H.: Statistics on Wave Heights and Periods for the North Atlantic Ocean. David Taylor Model Basin Report 1091, September, 1957

5. Hogben, N.; and Lumb, F.E.: Ocean Wave Statistics. Her Majesty's Stationery Office, 1967

6. Longuet-Higgins, M. S., "On the Statistical Distribution of the Heights of Sea Waves". Journal of Marine Research, Vol. XI, No. 3m p. 245-266; 1952

7. Bendix Marine Advisus, Inc.: Standard Wave Spectra for Open Sea Structures. 22 April 1969

8. Pierson, W. J.; and Moskowitz, L.: A Proposed Spectra Form for Full Developed Wind Seas Based on the Similarity Theory of S. A. Kilargorodskii. Geophysical Science Laboratory Report 63 - 12, New York University, School of Engineering and Science, October 1963

9. Myers, J. J.; Holm, C. H.; and McAllister, R. F. editors: Handbook of Ocean and Underwater Engineering. New York, McGraw Hill Book Co., 1969

10. Specification MIL-A-8862 (ASG, 18 May, 1960)

11. Federal Aviation Regulation, Part 27: "Airworthiness Standards: Normal Category Rotorcraft," U. S. Government Printing Office, Washington, D.C. 1968 (last revision)

12. U. S. Air Force Specification 518a. "Cargo Aircraft Compartment Dimensions Data"

LIST OF REFERENCES (cont'd)

13. GER 15213 Fabric Materials Test Program - Expandable Floating Bases

14. GER (to be published) Special Structural Problems of a Hexagonal Panel Deck

15. Mercier, John A.: Hydrodynamics Analysis and Exploratory Model Tests for an Expandable Floating Base. Stevens Institute of Technology. Letter Report SIT-DL-72-1579. January 1972